# ANNUAL REPORT **2025**



Introducing UMCA® Hickman, the Center's first black walnut cultivar release.

Center for Agroforestry
University of Missouri

# Content


| | |
|---|---|
| Letter from our Director | 4 |
| Our Team | 5 |
| 2025 at a Glance | 7 |
| Featured Impacts | |
| Marking a milestone: Mizzou Center for Agroforestry patents first black walnut cultivar | 8 |
| Taking on mining waste in Michigan's Upper Peninsula with fast-growing trees | 10 |
| North American Agroforestry Conference returns to Missouri roots | 12 |
| Outreach & Engagement | 14 |
| Research Briefs | 16 |
| Specialty Tree Crops | 16 |
| Forest Farming | 22 |
| Environmental Remediation | 23 |
| Soil Health | 26 |
| Silvopasture | 28 |
| Human Health | 29 |
| Graduate Programs | 33 |
| Publications, Presentations, and Funding | 34 |


**The University of Missouri Center for Agroforestry is recognized worldwide as a leader in agroforestry research.**

Since 1998, our scientists have investigated the impacts of integrating trees with crops and/or livestock on family farm economics, state and national-level conservation goals, and human health. Paired with curation and breeding activities for black walnut, chestnut, pecan, hazelnut, and elderberry spanning nearly three decades, our field research equips farmers with high performing cultivars that have the potential to boost farm gate revenue.

The Center educates the next generation of agroforestry leaders through the nation's first and only comprehensive agroforestry graduate degree. Outreach programming brings our latest research findings down to earth, with annual trainings, field workshops, and a robust network of demonstration farms in Missouri.

Our intertwined mission of research, education, and outreach works jointly to stand up profitable and resilient new tree crop industries and agroforestry innovations for family farms across the Midwest.


USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

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College of Agriculture, Food and Natural Resources
University of Missouri

School of Natural Resources
University of Missouri


We recognize that many concepts we embrace grow from the traditions of Indigenous peoples. We particularly indebted to recognize those tribes whose ancestral lands are in Missouri, including the Otoe-Missouria, Illini, Ioway, and descendants of Dhegiha Siouan peoples, including the Ponca, Kaw, Omaha, Quapaw, and notably, the Osage. Agroforestry applications continue to evolve and adjust to modern demands as we learn from practitioners and researchers with different backgrounds and worldviews. While this acknowledgment is simply a written statement, we are committed to including a myriad of perspectives in our work and to developing accessible educational programs. Our active work with Osage Nation at the MU Land of the Osages Research Farm is one way we demonstrate this commitment.


Center for Agroforestry
University of Missouri

Editors: Ben Brownlow, Hannah Hemmelgarn, Ron Revord, and Mallory Daily.

# Letter from our Director



This year marked a special milestone for us at the Mizzou Center for Agroforestry. The release of our first black walnut cultivar, UMCA® Hickman, is the culmination of three decades of work from our multigenerational team of tree breeders, which began with Dr. Mark Coggeshall in 2002, and is just the beginning for Missouri's industry for black walnut orchard nut production.

Another 'first' accomplished by our team in 2025 comes on the heels of four years of dedicated hazelnut breeding activities as a member of the Hybrid Hazelnut Consortium. For our inaugural hazelnut educational offering, more than fifty growers and technical assistance providers gathered with our hazelnut scientists and field specialists to learn about cultivar recommendations and orchard design specific to Missouri's soils and climate.

This year, we also had the special privilege of hosting the biennial North American Agroforestry Conference, a member gathering of the Association for Temperate Agroforestry (AFTA), a stalwart of our professional community since 1989. The collaborative, interdisciplinary nature of agroforestry professionals and practitioners was on full display through presentations, panels, and field tours spanning topics in horticulture, crop breeding, integrated farm design, management, technical assistance, adoption, economics, nutrition, conservation, and more.

These new activities are occurring at a critical inflection point for agroforestry nationwide, where additional investment and partnership will have profound and lasting positive impacts on farmer livelihoods and the natural resources on which we all depend. To that end, our team worked this year to create an ambitious 2026-2030 strategic plan to secure new sources of funding, identify research priorities, add new faculty lines, and enhance our educational offerings. The plan will be available on our website by the end of the first quarter of 2026.

Our work is made possible through countless collaborations across agriculture and conservation sectors. Foundational support for our core research activities continues through our agreement with USDA Agricultural Research Service, Dale Bumpers Small Farms Research Center in Booneville, Arkansas, which has advanced our work for nearly three decades. We extend our gratitude to all our partners, and look forward to continuing to advance agroforestry with you in the new year and beyond.

Sincerely,



Ron Revord, Ph.D.

# OUR TEAM



## Faculty



**Ron Revord**
Director and Associate Professor



**Chung-Ho Lin**
Research Professor



**Sam Lord**
Assistant Research Professor



**Michael Gold**
Professor Emeritus



**Ranjith Udawatta**
Professor Emeritus

## Affiliated Faculty



**Morgan Davis**
Associate Professor
*School of Natural Resources*



**Ben Knapp**
Associate Professor
*School of Natural Resources*



**Harley Naumann**
Associate Teaching Professor
*Division of Animal Sciences*



**Theodoros Skevas**
Associate Professor
*Division of Applied Social Sciences*



**Andrew Thomas**
Assoc. Research Professor
*Division of Plant Science and Technology*



**Kelly Wilson**
Asst. Research Professor
*School of Natural Resources*

## Staff



**Matthew Ashby**
Research Specialist



**Gina Beebe**
Edu. & Research Specialist



**Ian Boyd**
Snr. Research Specialist



**Mallory Daily**
Strat. Comm. Consultant



**Hannah Hemmelgarn**
Assistant Director



**Jericha Hervey**
Research Specialist



**Kira Kirk**
Event Coordinator



**Nick Meier**
Research Specialist Lead



**Liz Prenger**
Snr. Research Specialist



**Elizabeth Rogers**
Research Scientist



**Olga Romanova**
Tech. Assistance Provider



**Kelsi Stubblefield**
Edu. & Training Coordinator

## Postdocs



**Caroline Todd**
Business Specialist



**J. Bryan Webber**
Research Consultant



**Andria Caruthers**
Revord Lab



**Hernan Borrero Camacho**
Skevas Lab

## Interns



**Ben Brownlow**
SciComm Intern



**Amaya Morgan**
SciComm Intern



**Graduate Research Assistants:** (left-to-right) Tanner Rankin, Tharindu Rambadagalla, Aubrey Teckam, Ruth Williamson, Amanda Dwikarina, Nahom Ghile, Phuc Hong Vo, Pradeep Hitihamilage, Ren Klug, Raelin Kronenburg, Emmanuel Oppong Adjei. Not pictured: Dylan Sutton, Kendra Ezparza-Harris.

# SELECTED HIGHLIGHTS

Center for Agroforestry faculty and staff hosted more than 200 agroforestry professionals and farmers on Mizzou campus and surrounding sites for the **North American Agroforestry Conference (NAAC)** in July. Director **Ron Revord** was honored with the Association for Temperate Agroforestry's Research Award, while our Founding Director Gene Garrett was honored with the Legacy Award. The Center first hosted an annual NAAC conference in 1991.

Research Professor **Ranjith Udawatta** delivered the keynote address on his lab's thirty years of research into agroforestry's ecosystem services at the **16th Annual Agroforestry Symposium.** The program attracted more than 800 registrants around the world.

Research Professor **Chung-Ho Lin**, doctoral student **Elizabeth Rogers**, and alumni **Ryan Vinhal** were honored with the USDA Forest Service Chief's Honor Award for their project titled ***Enhanced Phytoremediation for Rural and Urban Communities***, led by Ron Zalesny, PhD.

**Ruth Williamson**, a first-year doctoral student in the Lin Lab, was awarded a **National Science Foundation Graduate Research Fellowship** for her work to understand how forested landscapes impact human mental health.

Participants of the **World Congress on Agroforestry in Rwanda** were brought a taste of Missouri during Associate Professor **Andrew Thomas**'s presentation on eastern black walnut for nut production. Thomas brought snack bags from Hammons Black Walnuts to share with the international audience.

**Our outreach team** worked collaboratively with eleven producers and nonprofit leaders to update the success stories in the ***Training Manual for Agroforestry Practices***. Updates were also made to nutrition handouts for the general public on hazelnut, black walnut, pecan, and chestnut.

The **Missouri Chestnut Roast Festival** brought together more than 1,500 visitors, 30 exhibitors, and our research and outreach teams for celebration of our state's perennial harvest and public education about agroforestry systems.

Research Professor **Chung-Ho Lin** participated in a panel of experts on soil remediation in war zones at the World Food Prize Foundation Borlaug Dialogue on Regenerative Recovery in Des Moines, Iowa.

Four members of **the Revord Lab** presented their work on tree crop breeding and horticulture at the IV International Symposium on Underutilized Plant Species in Fort Meyers, Florida.

Research Specialist **Bryan Webber** traveled to AMB Rousset's nut processing facilities in France to bring back insights for Missouri nut processing innovations during the fall harvest.

Our graduate program led by Professor Emeritus **Michael Gold** is currently serving 44 students with 14 graduations and 15 new enrollees during the 2025 calendar year.

# 2025
*at a glance*

**$3.98**
million in grant expenditures

**818**
people registered for the 16TH Agroforestry Symposium

**50**
Agroforestry Academy graduates

**57**
research and outreach presentations

**24**
peer-reviewed publications

**14**
M.S., Ph.D., & Certificate graduates

**901**
tree crop genotypes* conserved in our field repositories

**18,060**
chestnut, hazelnut, elderberry, pecan, and black walnut breeding progeny** under evaluation

**1,500+**
visitors to the Missouri Chestnut Roast Festival

*GENOTYPES refer to the genetic blueprint of an organism. Our repository is a collection of trees and shrubs with 714 distinct genotypes that show potential for climate adaption, disease resistance, high productivity, and more. These are characteristics that will support perennial crop industries for generations. **BREEDING PROGENY refers to trees and shrubs that are evaluated annually for their performance. In time, they will either be culled due to suboptimal characteristics or released as new cultivars or seed sources.



# MARKING A MILESTONE

## Mizzou Center for Agroforestry patents first black walnut cultivar

A new black walnut cultivar, UMCA® ‘Hickman’, is now available for high-quality orchard nut production, a new milestone in our tree crop improvement program that spans nearly three decades.

The Center’s tree crop geneticists began curating cultivars of nut-producing eastern black walnut (*Juglans nigra* L.) in 1996. A few years later, in 2002, Dr. Mark Coggeshall established the first generation of offspring to kick off our signature black walnut breeding program. Coggeshall served diligently as the program’s lead investigator until 2017. Today, the program includes:

- Breeding blocks with 3,000 progenies from 342 families under evaluation for future cultivar potential;
- 575 trees in cultivar trials for more immediate release; and
- 180 genotypes preserved across four repositories.

Our black walnut breeding program supports the continued development of a commercial black walnut industry in Missouri and surrounding states. We are well poised to release additional cultivars in the coming years along with horticultural and mixed species system recommendations for integrating black walnut into farms of all scales across the state.

> “Our hope is that our UMCA® ‘Hickman’ cultivar release will increase orchard adoption – and thus spur industry growth – as Hickman’s prolific bearing habit helps improve early yields and return on investment for growers.”

“Black walnut has great economic potential in Missouri and the Midwest,” said Ron Revord, director of the Center for Agroforestry. “Our hope is that our UMCA® ‘Hickman’ cultivar release will increase orchard adoption – and thus spur industry growth – as Hickman’s prolific bearing habit helps improve early yields and return on investment for growers.”

Missouri’s black walnut industry currently relies on nuts harvested from wild trees. While wild black walnut trees are abundant in Missouri and provide a solid backing for the industry, black walnut cultivars suited to orchard cultivation for nut production could help solve some of the industry’s biggest obstacles.

Black walnuts are a masting species, leading to inconsistent supply during non-masting years. Even in seasons with abundant production, nut size and quality can vary dramatically among wild trees, resulting in processing issues and price variations.

To support the walnut industry in Missouri, our breeding program looks for promising selections that exhibit the following characteristics:

- Nuts produced in spur-bearing* branches;
- High kernel percentage (i.e. large nut inside shell);
- High overall kernel yield per tree;
- Precociousness (i.e. tree begins bearing nuts early in life);
- Low defect rate;
- Light kernel color.

UMCA® ‘Hickman’ performs desirably in the majority of these categories. It is the highest-yielding tree among the 120 seedlings established in our 2002 breeding generation, as well as the earliest to bear nuts at five years old.

Compared to other available black walnut cultivars, UMCA® ‘Hickman’ produces high yields of desirable nuts early in life, continuing well into maturity. While it can alternately bear under low-input conditions, this tendency can be minimized with management, and average yields tend to outperform the most promising consistently bearing trees.

As ‘Hickman’ reaches maturity, yields are comparable to cultivars ‘Sparrow’ and ‘Neel’, surpassing typical yields of ‘Football’. Its kernel weight averages 5.1 grams with kernel percentage reaching 36 percent in years with ample rainfall in Missouri (wild nuts typically span 10-14 percent).

Missouri is uniquely poised to lead the domestic black walnut industry. Much of the infrastructure needed to process black walnut nuts already exists in our state. Hammons Products Company, established in 1946 and located in Stockton, operates the primary commercial shelling operation in the country with more than 160 hulling stations across 11 states. A majority of these stations are in Missouri.

Wild nuts fetch a price of about $0.16/lb of hulled in-shell nuts. Improved cultivars, on the other hand, receive a premium in-shell price of $0.50 to $1.20 per pound from Hammons (hulled and dried). Some growers have reported marketing cracked nuts or cleaned black walnut kernels direct-to-consumer with premiums ranging from $10 to $20 per pound.

“Landowners can cash in by including improved variety black walnut trees with their farm plan, managing them for quality and volume of nuts produced,” said Brian Hammons, president of Hammons Black Walnuts. “Black walnuts are one of the most sustainable, protein-packed, bold tasting ingredients in the food industry. They hit a lot of today’s food trends.”

Hammons estimates that the current market could support cultivation of up to 5,000 acres of improved cultivars, with a farm gate value of $1,000 to $2,400 per acre as trees mature (years 5-9). Yields can exceed 4,000 pounds in-shell per acre starting as early as year ten with ‘UMCA® Hickman’, with some tendency to alternate bear depending on management.

Farmland that is otherwise considered marginal for row crops, like bottomlands, is often well-suited for black walnut, offering yet another economic opportunity from a long-lived perennial for Missourians.



*Spur-bearing refers to nuts produced on short, compacted branches 4-12 inches in length along a primary branch (similar to apples), as pictured above on ‘Hickman’.

Coggeshall, M.V. Revord, R. S., & Meier, N.A. (2025). Walnut Tree Named ‘Hickman’ (United States Patent PP36382). The Curators of the University of Missouri (Columbia, MO, US).



Mark Coggeshall




Nick Meier



Ron Revord



# Taking on mining waste in Michigan's Upper Peninsula with fast-growing trees

In the early 1900s, over 6 billion pounds of copper ore processing waste, known as "stamp sands", were discarded into the Keweenaw Bay of Lake Superior, near the L'Anse Indian Reservation of the Keweenaw Bay Indian Community (KBIC), a Lake Superior Band of Chippewa Indians. Over several decades, wave action and currents mobilized the stamp sands and deposited them along the shoreline of Sand Point. This process continues today. The Sand Point site is of cultural significance to KBIC as a place where food and medicinal plants grow, and it serves as a gathering place for the community's Pow Wow and other events. In addition, there is a healing clinic, campground, marina, and other opportunities for education and recreation.

Shifting stamp sands are a concern because they contain heavy metals whose toxicity poses threats to human well-being and the health of the Sand Point ecosystem. Through Indigenous ways of knowing and implementing nature-based solutions, KBIC has led efforts to restore and recover Sand Point from this legacy of pollution left by the mining industry. Among these efforts, 34 acres of stamp sands along 2.5 miles of shoreline at Sand Point have been capped with soil and planted with native plant species. The once barren and now vegetated landscape offers beneficial insect and wildlife-friendly habitat, and walking trails have been established along the lake and wetlands for the community and its visitors to experience a healing landscape.

Karena Schmidt, ecologist with the KBIC Natural Resources Department, acknowledges the deep significance of the project. "We are asking much of the plants," said Schmidt. "To grow in dark toxic sands devoid of organic matter, be subject to the full array of intense sunlight, be exposed to the temperature extremes of summer and winter, and still they offer their gifts of floral beauty and medicine."

Most recently, Mizzou Center for Agroforestry researchers have partnered with the USDA Forest Service Northern Research Station, the KBIC, and Michigan Technological University to implement a phytostabilization and phytoremediation project at Sand Point. Funded by the U.S. Forest Service under the Ecosystem Restoration Provision of the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL) , this project uses specialized fast-growing trees and biochar to stabilize and remediate the stamp sands at the site.

This phyto project is the result of years of research by Ron Zalesny, PhD, supervisory research plant geneticist at the U.S. Forest Service, Elizabeth Rogers, PhD, research scientist at the Mizzou Center for Agroforestry, and Ryan Vinhal, MS, U.S. Forest Service forester and Center for Agroforestry alum. Initially developed in 2003, the team refined their method, called phyto-recurrent selection, to identify poplar and willow varieties that are uniquely suited to address restoration goals of degraded sites. In March 2023, their method of phyto-recurrent selection was adopted as a best practice within the United Nations' Decade on Ecosystem Restoration's "Framework for Ecosystem Restoration Monitoring" registry. The team used this method to select the most promising poplar and willow varieties to plant in the phyto systems at Sand Point.

In June 2024, nearly 3,000 willows and poplars were planted at Sand Point. In honor of the decades of restoration efforts preceding the buffer, project scientists worked with the KBIC to disturb as little vegetation from the site as possible.

"So, all of the native plants that exist at the site after nearly two decades of restoration work by the KBIC remain and surround the trees," said Rogers. "This was intentional, as we wanted to have the least disturbance as we could on the Sand Point ecosystem."

At the start of the project, the team collected soil samples at the site that are being analyzed by Research Professor Chung-Ho Lin, PhD, his lab team at the Mizzou Center for Agroforestry, and the MU Metagenomics Center. The samples are being used to assess the existing microbial community at the site in hopes of identifying microbes that are able to detoxify heavy metals.

"These toxic heavy metals cannot be degraded by microorganisms, but they can be transformed into less toxic forms by them," said Lin. "Planting trees at the contaminated site can stimulate microbial detoxification processes and help establish a cost-effective, environmentally friendly, and self-sustaining symbiotic remediation system."

Using metagenomics analysis, the team has identified 15 heavy-metal detoxifiers, including 10 heavy-metal-reducing bacteria and 5 heavy-metal-reducing fungi, in the soil samples. The team is working to map the spatial distribution of these microbial detoxifiers across the site. The team has successfully mapped the spatial distribution of heavy-metal contamination at the site. Now, the team is working to combine these spatial analysis tools to evaluate the effects of biochar and poplar treatments on heavy-metal detoxification and transport dynamics.

"Planting trees at the contaminated site can stimulate microbial detoxification processes and help establish a cost-effective, environmentally friendly, and self-sustaining symbiotic remediation system."

The team conducted two more soil sampling events during 2025, with sample analysis currently underway. Over time, the team will continue soil sampling efforts to better understand the composition of the microbial community at the site, and to monitor any changes that occur. The team has also begun taking measurements on the trees in the phytotechnology systems to assess the performance of the different poplar and willow varieties at the site.

"During the 2025 field season, our team began doing intensive physiological measurements on the trees," said Ron Zalesny. "One of our ultimate goals is to use the information that we generate from this project to develop best management practices for the sustainable management of similar sites that are affected by stamp sands in the region."

The Sand Point phyto project seeks to address the ecological restoration goals identified by the KBIC as well as enhance the beneficial uses of Sand Point to open up more pathways for recreation, cultural use, and wildlife habitat. In the years to come, the well-cared-for trees are expected to stabilize the stamp sands and lessen the toxicity of heavy metals within them, resulting in a healthier and more resilient lakeshore ecosystem for future generations to enjoy and depend upon.

Funding acknowledgement: Zalesny, R.S. Jr., Johnston, E., Lin, C-H., Rogers, E.R., Vinhal, R.A., Ballinger, J., Cai, Z., DuPlissis, J., Elder, T., Hallett, R.A., Heckman, K., Kane, E., Page-Dumroese, D., Paqueo, L., Piana, M., Schmidt, K., Sonti, N., and Yan, J. 2023-2028. Using specialized trees and biochar to remediate and stabilize mining waste for the Keweenaw Bay Indian Community. USDA FS Washington Office, Ecosystem Restoration Provision 40804(b)(8) of the Infrastructure Investment and Jobs Act, also known as Bipartisan Infrastructure Law. ($895,000).

# North American Agroforestry Conference
## returns to Missouri roots









In late-July, 200 agroforestry professionals, scientists, farmers, technical assistance providers, educators, and students arrived in Columbia, Missouri for the 19th North American Agroforestry Conference (NAAC). The biennial conference was last hosted in Missouri in 2009. A decade and a half later, our colleagues, peers, and partners joined us once again to brave the heat July 23-25 on the University of Missouri's beautiful campus and on nearby working farms and demonstration sites.

"Agroforestry science has come a long way over these decades, and we have a lot to show for ourselves here in Mid-Missouri" said Hannah Hemmelgarn, assistant director of the Center for Agroforestry and lead conference planner. "Hosting the conference gives us all an opportunity to connect the dots between our own and others' research, our collective impact, and how we can grow together."

As outgoing AFTA president, Hemmelgarn, AFTA's Board of Directors, and an inter-regional steering committee saw this year's conference as an important transition point for the agroforestry community. AFTA's original leadership and many of the faculty who led early research on agroforestry are now ushering in the next generation of agroforestry professionals; new organizations are responding to growing regional interest in perennial agroecosystems; and we recognize the need to learn from each other.

Towards that goal, the 2025 NAAC hosted more than 60 research presentations, 30 posters, 20 exhibitors, and visits to five nearby field sites. Connections deepened through events featuring a spectrum of voices and mediums: a film screening and discussion, an interactive arts-based event, and social networking. The conference theme, Inform the Future of Agroforestry, reflects the historical point where the agroforestry community now stands, honoring both new voices and early innovators. Participants represented a wider range of roles across agroforestry's economic and informational value chains than ever before at NAAC.

A dedicated planning team at the Center for Agroforestry, along with a steering committee of important partners across the US and Canada, thoughtfully detailed each aspect of the event, from conducting abstract review and synthesizing session track themes across disciplines, to planning catered meals with locally grown tree crops important to our region. Each element speaks to the maturing of our field from a purely academic inquiry space to one that touches on market development, adoption trends, and best practices for long-term management of these highly complex integrated agroecosystems.

For most conference attendees, this was their first NAAC; for others, the conference has been a long tradition spanning decades and evolving with changing conditions. By the end of the conference, all participants who completed an evaluation indicated that they would be "very likely" or "likely" to attend NAAC again, that they will follow up with new connections made at the conference, and that they expect to adapt, adjust, or improve their agroforestry-related efforts based on what they learned.

Since 1989, this conference has been an essential space for convening and reporting research spanning ecological, social, and economic dimensions of agroforestry across agencies, institutions, and regions. The University of Missouri first hosted the conference in 1991, an important precursor to the establishment of the MU Center for Agroforestry seven years later. At that time, our Founding Director Gene Garrett and future Associate Director Mike Gold came together with leaders in agroforestry science across temperate North America to envision the Association for Temperate Agroforestry (AFTA) which was founded in 1993 as an organizing body for NAAC in partnership with rotating hosts.

"Collaborations across disciplines and regions have always been integral to the field of agroforestry," said Mike Gold, now professor emeritus with the Center for Agroforestry. "Seeing the expansion of our group to include nonprofits, private business owners, farmers, communicators, educators, and more scientists than ever before is a testament to agroforestry's growing relevance and significance in North America's agriculture and natural resource landscape."

Throughout AFTA's history, Center for Agroforestry faculty and staff have served on the AFTA Board of Directors to contribute to its mission to grow and support a diverse and dynamic agroforestry community. Mike Gold served as the first AFTA president, Gene Garrett served as AFTA's second president, and following in their footsteps, Hannah Hemmelgarn completed her second term on the board, serving as president from 2023-2025, overseeing the 18th NAAC in Costa Rica and culminating her term with the 19th NAAC on home grounds. Andria Caruthers, one of the key organizers for this year's conference, is now carrying the baton as AFTA's Center for Agroforestry representative.

Our team extends special gratitude to the 2025 NAAC Steering Committee for their planning and facilitation contributions: Mark Batcheler (USDA National Agroforestry Center); Liz Rogers (US Forest Service and University of Missouri); Patrick Shults (Washington State University); Stesha Warren (Appalachian Sustainable Development); Augustine Osei (Saskatchewan Ministry of Agriculture); Sougata Bardhan (Tennessee State University); John Munsell (Virginia Tech University); and James Calabaza (Trees, Water, People); along with our staff Andria Caruthers, Kira Kirk, Hannah Hemmelgarn, Mallory Daily, and Caroline Todd.

Nineteen sponsoring organizations made the conference possible, including Minority Landowner Magazine, Missouri Rural Crisis Center, The Nature Conservancy in Missouri, Green Lands Blue Waters, Sustainable Forestry and African American Land Retention Network, AM Root Builders, Forrest Keeling, Stacked Agroforestry, River Hills Harvest, Trees for Graziers, Savanna Institute, Field & Forest Products, the Agroforestry Coalition, the Midwest Forest Farming Coalition, Central State University Extension, Columbia Center for Urban Agriculture, Indigenous Agroforestry Network, Ecotrust, and USDA Agricultural Research Service.

**Scan the QR code or click here to see more photos from the conference.**






Left: Mizzou Center for Agroforestry Director Ron Revord and Founding Director Gene Garrett received 2025 AFTA Awards for the impact of their work in agroforestry science and education. Top: Kira Kirk, Hannah Hemmelgarn, and Andria Caruthers served as lead conference planners for NAAC along with the Center's outreach team.

# Outreach & Engagement

Over more than three decades of applied research, we've grown deep roots in the Missouri River Hills. We showcase this work and cultivate community at field events like the annual fall Missouri Chestnut Roast Festival, the Agroforestry Symposium, hands-on workshops, learning circles, and at conferences across the region. This year, our annual Agroforestry Training Academy, established in 2013, surpassed a new milestone with more than 400 trainees to date.

Those trainees amplify our impact through their technical assistance and demonstration capacities, and sometimes go on to complete a graduate degree through our one-of-a-kind academic programs. These efforts have set the foundation for a supportive professional network of engaged partners across farms, universities, non-profit organizations, agencies, and industry that come together to amplify our collective impact.

Our year began with the hybrid **Agroforestry Symposium** (Jan. 30) and its accompanying Working Lands Learning Circle (Jan. 29). Centered on the theme, *Working Lands for Restoration and Harvest*, the program highlighted how agroforestry can transform landscapes with interwoven conservation, restoration, and production goals. Professor Emeritus Ranjith Udawatta, PhD, opened the event with a plenary synthesizing his 30+ years of research on agroforestry's ecosystem services. Additional speakers, including Susan Cook-Patton, PhD, The Nature Conservancy; Linda Hezel, PhD, RN, Prairie Birthday Farm; and Maile Wong, PhD Candidate, University of Hawai'i at Manoa, shared diverse perspectives spanning management, policy, and cultural food systems.

More than 100 people participated in-person and 700+ registered online, representing 300+ current and prospective agroforestry farmers and 200+ natural resource professionals. Fifty participants joined in-person for the Learning Circle, where small-group discussions helped translate the symposium's big ideas into practical applications.

Along with the thawing ground and budding plants, spring also brought about our annual **Agroforestry Training Academy**. During the first portion of the Academy, we invited participants to join us online for a five-week intensive course on biophysical site assessments, agroforestry species selection, management strategies, economics, marketing, and more. This year's cohort of 50 individuals consisted of technical assistance providers hoping to incorporate agroforestry into their daily work and land stewards planning to implement agroforestry on their own sites. During each week of the course, participants engaged with multimedia resources on agroforestry and joined Zoom sessions facilitated by 35+ seasoned agroforestry experts. The three-day in-person field experience allowed participants to hear from farmers operating a variety of agroforestry systems, species, and scales in mid-Missouri. Some of the sites included a chestnut and winter wheat alley cropping system, a community-focused urban forest garden, as well as sheep, pig, and cattle silvopasture systems.

On the heels of the Agroforestry Academy, our team welcomed 200+ agroforestry professionals to Columbia in peak summer heat for the **19th Biennial North American Agroforestry Conference (NAAC)**, July 23-25, a member gathering of The Association for Temperate Agroforestry (AFTA). Read more about NAAC on page 12.

Fifty growers joined our **Hybrid Hazelnut Workshop** at the MU Horticulture and Agroforestry Research Farm (Oct. 17) to explore cultivar selection, propagation techniques, and system design, with tours of our hazelnut field trials. Sessions were led by Rutgers University's Tom Molnar, PhD, along with our Director Ron Revord and members of his lab team, Aubrey Teckam and Bryan Webber.

The following day, 1,500+ people gathered with umbrellas in hand to celebrate our regional agroforestry community at the **Missouri Chestnut Roast Festival**. Over 30 vendors and exhibitors from specialty crop farms, conservation agencies, nonprofits, Extension programs, and local businesses welcomed visitors with tree crop tastings, educational exhibits, local foods, and artisan goods. Culinary experiences were at the heart of the festival this year, with roasted chestnuts, pawpaw ice cream, chestnut soup, elderberry lemonade, roasted hazelnut samples, and more. A taste of the Center's research efforts for forest farming included samples of four species of tree syrups, highlighting value-added Missouri forest products. Guided hay wagon tours carried guests through five of our research orchards to learn about chestnut, black walnut, elderberry, and silvopasture. Back at the main festival grounds, live music played while children created nature-themed crafts. When it finally rained at the close of the event, it poured; visitors departed with full bellies and fresh inspiration for how agroforestry can strengthen Missouri's landscapes, communities, and economies.

Shortly after the festival, we launched the **Certified Agroforestry Professionals (CAP) Program & Learning Network.** To date, more than forty individuals have completed their certification requirements and are now featured on our interactive map of certified agroforestry professionals and producers. In addition to this enhanced visibility for our region's agroforestry experts, CAP provides continuing education and networking opportunities to certified members. We expect the program to grow each year through engagement with our 500+ alumni across our training academy and graduate programs.

### Working Lands Learning Circle

Fifty producers and technical assistance providers attended our workshop on balancing productivity and restoration goals.



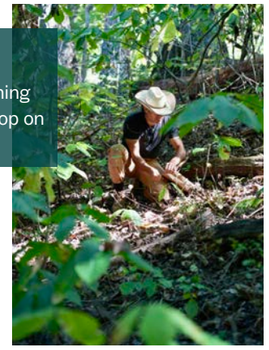
### The Agroforestry Symposium

More than 800 technical assistance providers, researchers, educators, nonprofit leaders, students, and producers registered for our program on Working Lands for Restoration and Harvest, with both in-person and remote participation opportunities.



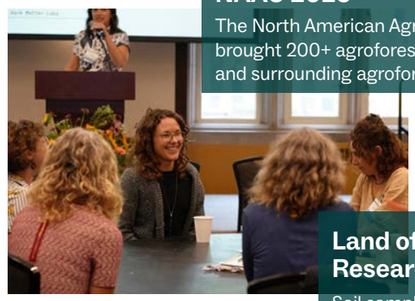
### Forest Farming Workshop

As a member of the Midwest Forest Farming Coalition, the Center co-hosted a workshop on cultivating ramps in Missouri woodlands.



### NAAC 2025

The North American Agroforestry Conference brought 200+ agroforesters to Mizzou campus and surrounding agroforestry farms and sites.



### Agroforestry Academy

Trainees visited Cedar Hill Farms' 16-year Chinese chestnut and winter wheat alley cropping system in Central Missouri.



### Land of the Osages Research Farm

Soil samples were collected from the farm to establish baseline data for future research.






### International Exchange

Research Specialist Bryan Webber traveled to France to explore AMB Rousset's 50-year legacy of tree nut processing innovations.




### Missouri Chestnut Roast Festival

1,500+ visitors sampled chestnuts and other perennial foods and interacted with 30+ exhibitors showcasing agroforestry products & services.




### Underutilized Plants Conference

Members of the Revord Lab traveled to the IV International Symposium on Underutilized Plant Species in Fort Meyers, FL to present on their work with tree crops.



### Hazelnut Workshop

More than 50 growers and technical assistance providers joined us for our first hazelnut workshop on cultivar recommendations and best growing practices for the Missouri climate.



# Research Briefs



## Specialty Tree Crops

### Overview of Tree Crop Breeding Programs at the MU Horticulture and Agroforestry Research Farm

Our tree nut and fruit breeding programs develop new cultivars for orchards and agroforestry systems, with the primary objective being nut/fruit quality, yield, and disease tolerance. In 2025, research scientists and field staff added 2,500 hazelnut, 1,000 pecan, 1,500 chestnut, 400 *J. regia*, and 500 *J. nigra* progeny to orchards at the MU Horticulture and Agroforestry Research Farm in New Franklin. A total of 51 black walnut progeny were culled from the breeding program due to small nut size or poor growth. This brings the total breeding progeny currently under evaluation to 18,060. Breeding progeny refers to trees and shrubs that are evaluated annual for their performance. In time, they will either be culled due to suboptimal characteristics or selected for advanced trails with potential to be released as new cultivars or seed sources.

Currently, our repositories house 901 unique genotypes across the various species for breeding and genetic conservation purposes. In 2025, we added 33 new advanced selections of hazelnut from Rutgers University as well as their six upcoming cultivar releases, 25 *J. regia* genotypes, 10 pecan cultivars, 3 elderberry cultivars, 40 persimmon cultivars (19 American, 4 hybrid, and 17 Asian), 30 mulberry cultivars, 20 pawpaw cultivars, and 20 serviceberry cultivars.

In addition to continued breeding efforts, our tree nut and fruit breeding lab is establishing and integrating agroforestry and production orchards for demonstration purposes. Projects initiated in 2025 include hazelnut, black walnut, and pecan silvohorticulture and silvocropping as well as a fruit silvopasture repository that will have potential for long study of silvopasture.

***Breeding blocks under evaluation***

- Chestnut (0-2 growing seasons): 4,000 progeny from 40 families, including 1,500 added in fall 2025;
- Hazelnut (0-3 growing seasons): 7,000 progeny from 102 families, including 2,500 added in fall 2025;
- Black/*J. intermedia*/*J. regia* walnut (1-21 growing seasons): 3,000 progenies from 342 families, including 900 added and 51 culled in 2025; and
- Elderberry (1-3 growing seasons): 3,300 progeny from 25 families.

***Cultivar/Selection Trials***

- Hazelnut (one trial, 0-4 growing seasons): 481 trees, 129 clones/checks, including 39 added in fall 2025
- Black Walnut (three trials, 0-20 growing seasons): 575 trees, 75 clones/checks
- Pecan (two trials): 124 trees, 25 clones/checks
- Chestnut (one trial): 73 trees, 10 clones/checks
- Elderberry (two trials): 63 clones/checks

***Repositories***

- Chestnut: 300+ genotypes
- Black Walnut: 180 genotypes
- Chinkapin: 100 genotypes
- Pecan: 90+ genotypes
- Elderberry:  30 genotypes
- Pawpaw: 3 genotypes
- Butternut: 20 genotypes
- Hickory/Hican: 40 genotypes
- Honey Locust: 5 genotypes

***Production & Demonstration Orchards***

- Two chestnut production and agroforestry demonstration orchards (est. fall 2024 & fall 2025)
- Hazelnut production orchard (10×16' spacing) with 106 'Raritan' (Rutgers release), 106 'Somerset' (Rutgers release), 106 hybrid pollinators ('The Beast', 'Grand Traverse', 'Geneva', 'Nitka')
- 'Raritan' Hazelnut Alley Crop (20' alleys, 40' alleys, and double row 20' alleys)
- Pecan cultivar trial (40' alleys)
- Fruit tree dual purpose silvopasture cultivar repository with mulberry, persimmon, serviceberry, and pawpaw

*—Nick Meier, Bryan Webber, Matthew Ashby, James Ian Boyd, Aubrey Teckam, Elizabeth Prenger, Ron Revord*

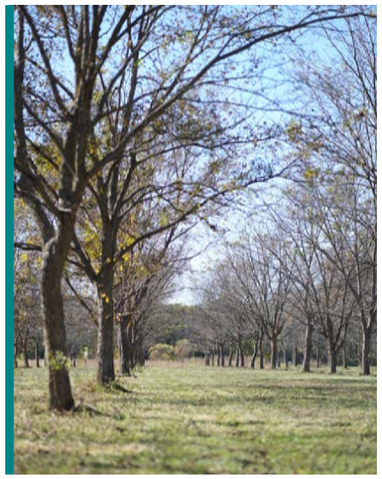
### Big kernels for big returns: New large kernel black walnut breeding selections

The American walnut (*Juglans nigra*), also known as the eastern black walnut, black walnut or the American black walnut, is a highly sought after species native to much of eastern North America. The nuts have a unique bold earthy flavor, are regionally popular and are used for baking, snacking, ice cream ingredients, and much more. Nutritionally dense, American walnuts are an excellent source of essential and non-essential amino acids, vitamin B9, B5, A, Fe, Zn, Mg, Mn, Ca and many other important nutrients. American walnuts also have many cardiometabolic protective compounds that can decrease LDL-cholesterol, reduce cardiovascular risk, prevent diabetes, reduce cancer risks, prevent chemically induced liver damage, support brain health, and enhance cognitive function in aging.

The Center for Agroforestry's American Walnut improvement program (AWIP), now in its 23rd year, has been fully engaged in the domestication and commercialization of *Juglans nigra*. Focused breeding targets for increasing kernel size, overall kernel quality, shelling efficiency, thinner shells, and yield (spur bearing habit) has resulted in our first release, the UMCA® 'Hickman' walnut cultivar, which is well suited to orchard production and was chosen for release due to prolific early bearing and high-quality, medium-sized kernels (~5g kernel mass, 30-36% kernel). Read more on page 8. *—Nick Meier, Bryan Webber, Matthew Ashby, James Ian Boyd, Ron Revord and Mark Coggeshall*

### Laying the groundwork for pecan: traditional cultivar trials and new breeding efforts

Pecan (*Carya illinoinensis*) is the most economically significant native nut species produced in North America. The US and Mexico account for more than 90% of the global supply. In the US, annual production fluctuates year-to year due to weather impacts and pest or disease outbreaks. Average annual yield over the past 5-years exceeds 274 million lbs., with a farm gate value of $455 million ($1.66/lb.), Mexico's production volume is comparable (40-55 percent of global supply) to that of the US, amounting to a nearly $1 billion North American industry. The Center for Agroforestry's Pecan Breeding and Genetics program is a new dedicated effort that builds on decades of germplasm curation and cultivar trialing. The primary objective is to promote increased pecan acreage in the northern parts of the native range, and to develop new cultivars well suited to Missouri and similar growing regions. Dedicated regional breeding programs are needed, in this case to support the expanding northern production region, to ensure growers have access to superior orchard trees that maximize production and profitability.



*A pecan research orchard at the MU Horticulture and Agroforestry Research Farm, New Franklin, Mo.*

In 2025, our scientists established our program's first breeding generation of 1,000 pecan seedlings (called 'breeding progeny') that will be evaluated to develop scab-resistant, large kernel cultivars to support the long-term success of the Missouri pecan industry. We've also established trials with new cultivar releases intended for northern regions from the USDA ARS College Station, TX. These trials will include integrated tests on how annual crops like rice, melon, and winter wheat perform within pecan orchard systems to demonstrate how revenue can be generated while trees are maturing. *—Nick Meier, Bryan Webber, Matthew Ashby, James Ian Boyd, Ron Revord and Mark Coggeshall*

### Chestnut curious: Understanding the establishment and management practices of chestnut growers

The chestnut industry is growing rapidly in the Eastern and Midwestern U.S. as more people become interested in planting this emerging crop. People are entering the industry from diverse backgrounds and often without agricultural experience, which has led to a wide range of practices used by chestnut growers in the establishment and management of their orchards. This research project aims to close this knowledge gap through a combination of social science and field research activities. In 2025, we started conducting interviews and surveys with chestnut growers to better understand the practices they use, their motivations, and pain points they experience. The first in a series of three surveys was released in fall 2025 and covers pre-planting considerations, grower expectations, and site preparation. Growers have shown a keen interest in these surveys and their results – to date, the first survey has over 130 participants and is still growing. Preliminary results are expected in Spring 2026 and will be released in conjunction with the second survey in the series, which will cover management topics such as tree protection, fertilizer usage, and pest management. The final survey will focus on how growers process, market, and sell chestnuts and is expected to be released in Fall 2026. In conjunction, two field experiments will be established at the MU Horticulture and Agroforestry Research Farm that address management topics within chestnut orchards. The first will focus on the effects of different tree protection methods, including fencing, tree tubes of various sizes, and wire cages. The second will focus on ground cover species that mix well with chestnut trees, including non-native and native grasses and clovers. Results of these different social science and field research activities will be communicated directly with chestnut growers in the years to come to aid them in their establishment and management decisions and help grow this new American industry. *—Tanner Rankin, Ron Revord*

### Advancing chestnut tissue culture

Our plant tissue culture lab allows our scientists to make genetic clones of chestnut trees in a lab setting, which will improve our chestnut breeding program as well as support commercial growers. Traditional propagation methods for chestnuts include grafting and planting by seed. These methods can work for small orchards but create challenges for large-scale production. Planting seeded chestnuts creates genetic variability within an orchard, making it difficult to anticipate how the trees will perform. Grafting can help, but this method also takes a lot of time and effort, and is not always successful. Tissue culture offers solutions to these issues by quickly producing a large number of plants that are also genetic clones. This means growers can expand their operations and researchers can test new varieties under the same conditions.

This year, we successfully started tissue cultures for three Chinese chestnut varieties. This success was achieved with help from our colleagues and through the optimization of our methods. Now, these cultivars are being increased through micropropagation, and we're on track to produce even more material for future work. Our next step is to grow enough shoots through micropropagation to start rooting trials. The goal is to produce shoots with roots that

can be adapted to grow into young trees in outdoor conditions. Clonal trees are useful for field trials to test performance and traits, and will provide our breeders with a reliable way to test different chestnut varieties. It will also open opportunities for growers to plant larger orchards with uniform, high-quality trees. Through these advancements in chestnut tissue culture, we are building the foundation for stronger breeding programs and large-scale production. This work will make chestnut growing more efficient and ensure a sustainable future for this valuable tree crop. *—Jericha Hervey, Ron Revord*

## Insights from hazelnut growers and prospective growers: Production systems, markets, and barriers in an emerging industry

Hazelnuts are an emerging perennial crop for farms seeking diversification, resilience, and higher-value products, yet relatively little is known about who is growing them, how they are managed, and what constrains further adoption and enterprise development. To address this gap, we conducted a cross-sectional survey of 113 current and prospective hazelnut growers. The instrument captured production scale and experience, management and production systems, current and planned markets, and perceived challenges and support needs.

Most respondents (~ 90%) were already growing hazelnut trees in 2024, while the remaining non-growers almost all planned to establish plantings or were considering doing so. Plantings ranged from small homestead plantings to larger orchards: among those reporting acreage, hazelnut area averaged just over 4 acres (median 1 acre), with a mean of roughly 930 trees (median 175 trees) and a maximum of 24,000 trees on a single operation. Respondents had been growing hazelnuts for a mean of about 7 years, underscoring that this is an emerging but not entirely nascent industry. Self-identification reflected a mix of orientations: roughly 40% described themselves as hobby/homestead or lifestyle growers, about one-quarter as commercial growers, and another quarter as both. Most production systems were non-certified organic or in conventional management, with fully certified organic systems representing much smaller shares. Orchards commonly were clonal cultivars only or combined clonal cultivars with seedling pollinizers or diverse mixes of clonal and seedling material.



*Hybrid hazelnut selection trial at the MU Horticulture and Agroforestry Research Farm. Photo by Aubrey Teckam.*

Marketing patterns illustrate both the early stage of the industry and growers' aspirations for their enterprises. While 41 growers indicated they harvested chestnuts in 2024, only roughly one-third of those respondents reported actually marketing hazelnuts in 2024. These respondents relied on a small set of primarily local, direct channels such as farmers markets, on-farm sales, local groceries, processors, and a handful of online or "other" outlets. In contrast, stated plans for future marketing are broader: among 84 respondents who answered the future sales question, just over half indicated they plan to use on-farm direct sales to consumers, about one-third plan to sell at farmers markets, and roughly one-quarter each anticipate working with cooperatives or other niche channels. Around one-fifth expressed interest in selling to wholesalers or through online/e-commerce channels, and a similar share identified local grocery stores, specialty food stores, and processors as part of their intended future marketing mix.

Perceived challenges highlight both infrastructural and market-development needs. Across 15 barrier-related questions in the survey, access to processing stands out: about 30% of respondents rated it as a moderate challenge, and another ~37% rated it as a significant or major challenge, meaning roughly two-thirds see processing access as at least a considerable challenge. Given that limited access to processing is viewed this way, it may also help explain growers' relatively low preference for selling to processors as a future sales channel. Limited marketing and distribution channels, labor availability and costs, delayed return on investment, high input costs, and low market prices also ranked among the most frequently cited significant or major challenges, while pests, diseases, and extreme weather were widely viewed as moderate concerns. Together, these results suggest that strengthening processing and aggregation capacity, coordinated marketing channels, and tailored technical assistance could substantially reduce risk for both commercial and lifestyle-oriented producers. By focusing on the experiences of current and prospective hazelnut growers, these preliminary survey results offer a wide lens view of production, markets, and constraints. These findings can help inform research efforts for a strengthened and more developed US hazelnut industry. *—Andria Caruthers, Teo Skevas, Hernan Borrero Camacho, Ron Revord*

## Updates on hazelnut cultivar development with the Hybrid Hazelnut Consortium

Hazelnut (*Corylus* spp.) production has historically been limited in the eastern and Midwestern United States due to presence of eastern filbert blight (EFB) caused by the parasitic fungus *Anisogramma anomala*. Global production primarily relies on the European hazelnut (*C. avellana*) for large, high-quality kernels, but is susceptible to EFB. As the endemic host of *A. anomala*, the American hazelnut carries an innate resistance/tolerance to EFB but has small, thick-shelled kernels, limiting commercial value. Tolerance, or quantitative resistance (QR), is presumed to be more durable to diverse fungal strains at high pressures in native ranges; emerging strains have overcome single gene resistance sources found in most *C. avellana* cultivars. Fortunately,



*Advanced selections of American elderberry at the MU Horticulture and Agroforestry Reseach Farm.*

decades of collecting, screening, and selecting *C. avellana* and *C. americana* germplasm at Oregon State (OSU) and Rutgers Universities (RU) have led to the production of thousands of offspring with EFB-resistance and high kernel quality. Efforts have culminated to release several new cultivars in recent years including *C. avellana* 'Raritan' and 'Somerset' and *C. avellana* × *C. americana* 'OSU 541.147' "The Beast", as well as the upcoming release of new *C. avellana* cultivars carrying QR. Additional cultivar releases are crucial to add climate and disease resiliency in new eastern orchards. Cultivars must have these adaptations by carrying diverse and durable EFB-resistance, appropriate bloom phenology, and self-incompatibility (S) alleles compatible with a wide variety of cultivars. There is an apparent challenge to recombine kernel qualities with resistance in the F1 interspecific hybrid generation; recombination in the F2 is possible but rare. As a result, hybrid production cultivars are unlikely to be released; hybrids will fill a valuable role in releasing pollinizers with early, mid, and late stages of bloom to ensure complete pollination of production cultivars even with interannual shifts in bloom time. Over 80 late-stage F1 hybrid selections were established in a replicated trial in 2021 at the Horticulture and Agroforestry Research Farm in New Franklin, Missouri. Selections are being evaluated for bloom time, yield, and kernel qualities for future pollinizer release. Precocious individuals bearing a critical mass of >30 nuts were harvested for the first time this fall. Additional selections and upcoming releases from RU were added to the trial in fall of 2025. *—Aubrey Teckam, Ron Revord*

## Building an American elderberry breeding program to support an increase in domestic production

Elderberry is a specialty crop that is gaining popularity due to its potential health benefits. However, elderberries have been used culturally and medicinally by people around the world for millennia. Elderberry fruit and flowers can be made into juice, supplements, powder, jam, pie, wine, and liqueur. These products are gaining popularity as healthier diets with functional food ingredients become more appealing. Current demand for elderberry products in the US is met by importing elderberries from Europe.

Researchers and producers across the US are working together to bring American elderberry to mainstream markets (SCRI project 2021-51181-35860). One of the ways we can support local production of American elderberry is by developing new cultivated varieties, or "cultivars" through a classic plant breeding approach. Current cultivars were developed in the northeastern US and Canada over 60 years ago or were selected from the wild in the Midwest, leaving plenty of opportunity for improvement. Our scientists are building on several decades of American elderberry research to develop new cultivars that will reliably produce good quality fruit in Midwestern environments.

The elderberry breeding program started with fruit harvest from commercially available high-performing cultivars and other plants that showed promise for orchard production. The seeds from these fruits were stratified, and just over 2,000 genetically unique seedlings were planted in the fields at the MU Horticulture and Agroforestry Research Farm (HARF) and Southwest Research Center (SWC) in 2022. Elderberry plants bear fruit relatively young, so researchers were able to evaluate the plants for their ability to produce fruit starting in 2023. After several years of observation, the most promising plants became advanced selections, which were put into performance trials at the HARF and SWC in the summer of 2025. Performance in these trials will help researchers determine which plants might produce well in growers' fields, eventually leading to cultivar release. These new cultivars should meet growers' and consumers' needs for cultivars that increase production, harvest efficiency, and fruit quality.

New crosses that pair up parents with desirable traits are done each summer. Each round of crosses begins a new breeding cycle that enables continuous improvement and response to the needs of growers and consumers of elderberry. An additional 2,000 genetically unique seedlings are being evaluated on an ongoing basis and will be included in the next round of replicated trials. Exciting things are coming down the pipeline in American elderberry research and breeding. New cultivars could be available to growers within the next five years that will support expanded domestic production of a native, adapted crop with great potential for positive impacts on human health. *—Liz Prenger, Nick Meier, Andrew Thomas, Ron Revord*

## Advancing American elderberry through international collaboration

The unfolding opportunities with American elderberry production, processing, and marketing in the U.S. fostered the receipt of a major grant in 2021 from the USDA Specialty Crop Research Initiative. This grant (continuing through 2026) has now propelled elderberry to the forefront of regionally grown specialty crops, and by 2025 has culminated in numerous scientific papers and presentations around the globe. The interdisciplinary Advancing Elderberry team hosted the Second International Symposium on Elderberry, June 2025, in Columbia, Missouri, bringing together 200 of the finest global elderberry minds (farmers, processors, marketers, and scientists) for a very high-energy gathering. One of the major goals of the event was farmer-scientist collaboration and connection. Elderberry research in weed management,

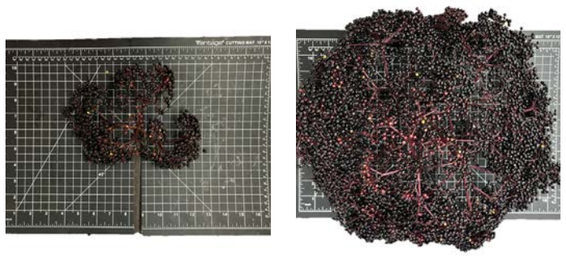
cultivar evaluation, breeding, pollination, mechanical harvest, food science, product development, economics, natural products chemistry, metabolomics, and brain health continues. Project partners include North Carolina State University, British Columbia Institute of Technology, University of Minnesota, University of Arkansas, Lincoln University, Missouri State University, Auburn University, The U.S. Pharmacopeia, Missouri Botanical Garden, Kerr Center for Sustainable Agriculture, and the Savanna Institute (among many others). The project website is: www.elderberry.missouri.edu. *—Andrew Thomas*

## Phenological development of American elderberry cultivars has implications for orchard design and breeding

Between 2017 and 2022, the number of elderberry farms and acres planted in the United States more than doubled. As elderberry becomes more popular, growers need reliable information to help make decisions about how to plant their orchards and produce high quantities of good quality fruit and flowers. Since elderberries do not self-fertilize, orchards and home garden plantings often include at least two different cultivated varieties, or "cultivars" so that fruit set is not dependent on pollen from wild plants. Information about each cultivar's flowering and ripening period helps growers make decisions about which cultivar combinations may work well in an orchard or garden. From a cultivar development perspective, this information can identify cultivars with desirable traits that elderberry breeders want in a new cultivar release.

An understanding of flower and fruit development is especially important for new plant materials not yet tested in orchards. At the Center for Agroforestry, an experiment with twelve different cultivars was grown at five locations beginning in 2022. Three of the cultivars are already available commercially, while nine of them were chosen for their production potential. For three years, data were collected at up to three locations to characterize flowering and fruiting patterns. Observations included dates of beginning of flower development, beginning of pollen shed, percentages of bloom across a plot, final bloom, and beginning of ripening. In 2025, individual flower heads, or umbels, were tagged at the Horticulture and Agroforestry Farm in New Franklin, Missouri, and the same data were collected on these individual umbels, along with percentage of fruit ripening over time.

At the plot level, these data illustrate flowering and ripening windows that may be seen in an orchard. An umbel does not flower or ripen all at once, but the whole umbel is harvested at one time, so flowering and ripening across the umbel can be helpful for identifying cultivars that ripen quickly and may be less likely to lose fruit. Across most years and locations, many cultivars in the genotype by environment interactions (GxE) had good overlap in pollen shed. However, 'Ranch' typically blooms earlier than other cultivars and 'Hamilton' finishes blooming later, indicating opportunities to develop high-performing cultivars with flowering windows similar to these varieties to support fruit set. Of the three commercially available varieties, 'Ranch' reached peak bloom (50% of flowers in plot open) an average of 6 to 13 days earlier than 'Bob Gordon' and 8 to 21 days earlier than 'Pocahontas'. Growers wishing to include 'Ranch' in an orchard may need to include another cultivar with earlier flowering times to maximize pollen availability and fruit set. A goal of the breeding program is to identify plants within the breeding program that have flowering windows complementary to 'Ranch'. Within individual umbels, 'Cherokee' and 'Pocahontas' had relatively long flowering times and short ripening times, which may be beneficial for fruit set (long flowering) while reducing fruit loss (short ripening). Cultivars with short bloom and short ripening windows included 'Ranch', 'Delight', 'Bob Gordon', and 'Barber'. These cultivars may serve as sources of desirable phenology traits for breeding. *—Liz Prenger, Sydney Moore, Andrew Thomas, Ron Revord*



*Left: Measurements of a ripe umbel from the cultivar 'Bob Gordon', a wild selection that was publicly released in 2011. Right: Measurements of a ripe umbel from the cultivar 'Pocahontas', a wild selection that was publicly released in 2019. Photos by Liz Prenger.*

## Elderberry economics: Insights into producer and consumer behavior

Our work examines economic behavior along the U.S. elderberry value chain, focusing on consumer demand and producer decision-making. Although elderberry production has expanded rapidly in recent years, limited empirical evidence exists on the mechanisms shaping demand and on-farm management choices. The three studies summarized here address these gaps using consumer and producer surveys, econometric modeling, and field-based economic analysis.

The first study analyzes consumer demand for elderberry products by jointly examining attitudes and socioeconomic characteristics. Using a national U.S. survey, consumers were segmented based on their views regarding health benefits, social and environmental considerations, taste, and price. The analysis distinguishes between the likelihood of purchasing elderberry products and the frequency of consumption. Results show that socially conscious and health-motivated consumers are significantly more likely to purchase elderberry products, while consumption frequency is higher across all non–health-indifferent segments. Socioeconomic factors—including age, income, education, race, and family composition—also shape both decisions. These findings highlight the importance of distinguishing between drivers of initial market entry and those that sustain regular consumption, providing a framework for differentiated marketing strategies.

The second study examines the adoption of pest management practices among U.S. elderberry producers. Using survey data, the analysis compares the influence of objective, field-based pest indicators and subjective perceptions of pest severity. Results show that the number of distinct pest types observed in the field is a strong predictor of both adopting pest management practices and using multiple methods, while perceived severity alone does not explain behavior. Producer associations play a central moderating role by dampening reliance on subjective alarm and strengthening responses to observable pest conditions in both adoption and diversification decisions. These findings indicate that collective structures are especially effective in promoting disciplined, proportionate pest management through shared standards, peer learning, and accountability.



The third study evaluates the economic performance of alternative weed management strategies in American elderberry production using multi-year field experiments conducted at two sites in Missouri. A partial budget analysis compares costs, revenues, and profitability across six weed control methods. Herbicide and woodchip mulch treatments consistently generate high profitability across sites, while cover crops and unmanaged treatments perform poorly and often result in losses. Woven fabric performs well at one site but less so at the other, with differences driven primarily by yield variation rather than cost differences. Overall, yield outcomes are the dominant factor explaining profitability differences among weed management strategies.

Together, these studies provide complementary evidence on how elderberry markets and production systems operate. Consumer participation depends on distinct motivations at different stages of purchasing, while producer decisions and economic outcomes are shaped by observable agronomic conditions and access to collective information systems. By linking consumer behavior, on-farm decision-making, and economic performance, this work offers actionable insights for improving market development, extension efforts, and management strategies in the growing U.S. elderberry sector. *—Hernán Borrero, Theodoros Skevas*

## Expanding field infrastructure for horticultural management and mixed-species system research

A cornerstone of the Center for Agroforestry's mission is our specialty crop breeding program working to evaluate existing cultivars, new cultivars, and candidate releases in late-stage development for improved production characteristics, regional adaptability, and application in agroforestry systems. Field infrastructure for research on horticulture best management practices and mixed species systems is being established in concert at the Horticulture and Agroforestry Research Farm. Specialty crops, including chestnuts, pecans, hazelnuts, and black walnuts, serve as infrastructural crops to provide long-term profitability to agroforestry systems.

Our team has been building resources to support research on horticultural management practices and recommendations for specialty crops in the Missouri Riverhills growing region. Many of these specialty crops can be integrated without displacing the existing agricultural systems by using agroforestry methods such as alley cropping and intercropping. These practices are designed to maximize land-use efficiency and help offset cropping transition costs by maintaining current enterprises while layering in additional investment. Research priorities are shaped by industry needs to ensure investment in this resource generates an outsized return for growers and industry development with application at various scales.



*Strawberries, asparagus, and alfalfa hay in the hazelnut alley cropping trial at the MU Horticulture and Agroforestry Research Farm, October 2025. Photo by J. Bryan Webber.*

A key project that has been established for horticulture management practices is the hazelnut production trial with three ground cover treatments and a fertility response curve. This trial is planted with the Rutgers Landmark® series cultivar releases 'Raritan' and 'Somerset' and pollinizers with ground cover and fertility treatments including fescue, fescue/clover, and alfalfa/clover. Treatments of nitrogen fertilizers include 3 concentrations of urea and calcium nitrate. This trial will provide valuable information on the performance of these new hazelnut cultivars in Missouri, our best recommendations on which ground covers to establish, and the fertility rates that will maximize hazelnut production.

A key project established for the mixed species systems research priority is the hazelnut alley cropping trial. This trial was established with the cultivar 'Raritan' as the primary production cultivar along with pollinizers. The rows are spaced at 40 ft, 30 ft,

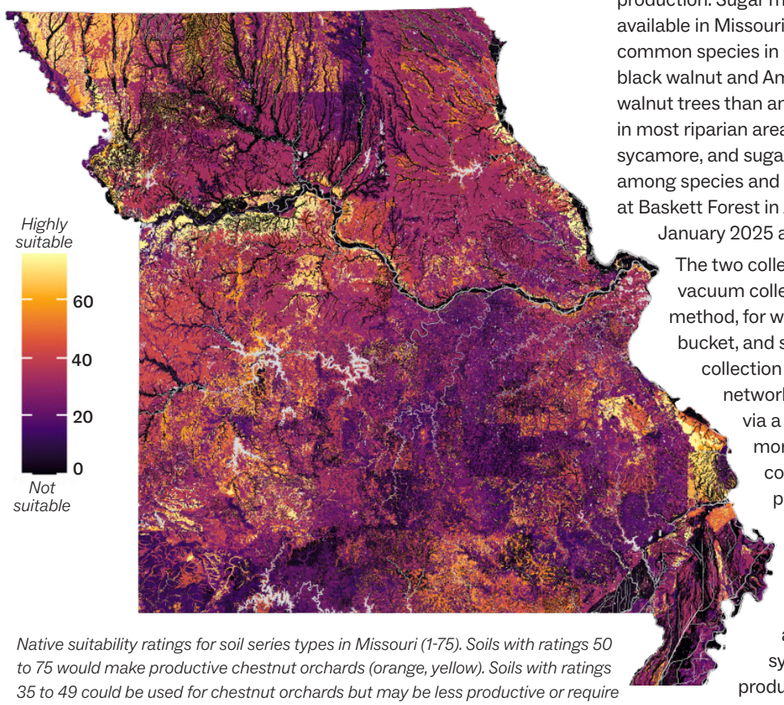


and 20 ft between rows and 10 ft within rows. This trial is modeling alley cropping production systems of nut trees with Missouri commodities (wheat and alfalfa) in the 40 t and 30 ft alley ways as well as high value alternative specialty crops (asparagus and strawberries) in the 30 ft and 20 ft alley ways. This trial serves as a demonstration of alley cropping agroforestry and will provide valuable insight into the land equivalent ratios for these cropping systems, above and below ground competition vectors that are at play, and the economics for variations of a hazelnut alley cropping system. *—J. Bryan Webber, Ron Revord*

### Tree nut crop soil suitability mapping for Missouri Riverhills and beyond

The Missouri Riverhills region is the deep, fertile, wind-blown loess, hilly landscape found adjacent to the Missouri and Mississippi Rivers. This growing region has the potential to become a major production region of high value horticultural and specialty crops, particularly deep-rooted, long-lived tree nut crops as high value, perennial alternatives to annual crop production. The Missouri Riverhills offers a soil composition and growing environment uniquely suited for horticultural and specialty crop production. Although fertile and recognized as prime farmland, the ridge tops and slopes of this hilly region are difficult to cultivate in an annual crop rotation due to steep slopes and issues with erosion. Many parcels are used as pastureland or have reverted to forest particularly where there are irregular parcel shapes, sizes, or steep slopes. Horticultural crops with tree nuts as permanent crops, including chestnut, hazelnut, pecan, and black walnut, can offer Missouri growers a high value opportunity for this class of land while providing an alternative and complementary source of income. Information is needed on the spatial distribution of the ideally suited land as well as the current land use status of these soil types. This project uses spatial analysis tools to map the ideal soil conditions for chestnuts, hazelnuts, black walnuts and pecans within the Missouri Riverhills growing region and to analyze recent land use on these soils to target land suitable for tree crops and agroforestry systems. Additionally, analysis of native soil characteristics to develop a crop suitability index can help to identify additional soil series and areas outside of the Missouri Riverhills that are also highly suitable for tree crop production. The first approach took seven known high quality soils for chestnut and hazelnut production (Menfro, Sibley, Wakenda, Monona, Kliever, Marshall, Knox) as well as 9 known high quality soils for pecan and black walnut production (Nodaway, Fatima, Napier, Jemerson, Motark, Dameron, Sturkie, Haymond, Racket) and determined all the competing soil series which look and behave the same way but are known under different names. The chestnut and hazelnut soils list went from seven soil series to 125 soil series, and the pecan and black walnut soils list went from nine soil series to 71 soil series. Chestnut and hazelnut suited soils are mostly concentrated in the Missouri Riverhills region, whereas the black walnut and pecan soils are more dispersed across the state with high concentrations in the Missouri Riverhills bottomland. The second approach was to create a soil suitability index by ranking the soil series on a 1-75 scale based on native soil characteristics including root depth, available water holding capacity, drainage class, slope, soil pH, and flooding frequency. This approach gives higher resolution to our understanding of the ideal soils in the MO Riverhills and points us towards suitable soils across the entire state, significantly increasing the production potential of the state. More fine tuning and ground truthing is needed in this model to establish official soil recommendations for each of the four tree nut crops. *—J. Bryan Webber, Ron Revord*

***Missouri Soils - Chestnut Suitability Ratings***




*Native suitability ratings for soil series types in Missouri (1-75). Soils with ratings 50 to 75 would make productive chestnut orchards (orange, yellow). Soils with ratings 35 to 49 could be used for chestnut orchards but may be less productive or require additional inputs/ amendments (pink, red). Soils with ratings 0 to 34 are generally not recommended for chestnut production (purple, black).*

## Forest Farming

### Syrup in Missouri – more than maple

Sugar maple is the tree species most commonly tapped for syrup production. Sugar maple trees large enough to tap are not widely available in Missouri outside of the Missouri River Valley. More common species in Missouri can be tapped for sap, including black walnut and American sycamore. Missouri has more black walnut trees than any other state and sycamores are common in most riparian areas. Last winter, we tapped black walnut, sycamore, and sugar maple trees to compare sap production among species and collection methods. Our research took place at Baskett Forest in Ashland, Missouri. We tapped trees in mid-January 2025 and concluded sap collection in early-March.

The two collection methods we tested were bucket and vacuum collection. Bucket collection is the traditional method, for which each tapped tree has an individual bucket, and sap flows out of the tree via gravity. Vacuum collection systems connect many trees to one tubing network and create negative pressure in the line via a water pump. Vacuum collection can be more efficient than buckets, as there is only one collection tank for many trees and the negative pressure can increase sap yields.

We measured the sap sugar content and yield for each tapped tree. Sugar maples produced the sweetest sap, followed by black walnut, and sycamore. Sugar maples also yielded more sap than black walnuts and sycamores in bucket collection. Sycamore trees produced almost no sap in bucket collection.



The use of vacuum did not influence sap sugar content but did influence sap yields. For sugar maples, the sap yield doubled with vacuum collection compared to bucket collection. Vacuum collection did not appear to change sap yields in black walnut trees. Sap yields increased most dramatically in sycamore trees, from 0.37 gal/tap with bucket collection to 13.3 gal/tap with vacuum collection. We had to purchase a larger collection tank for the sycamore line because each tree was producing nearly a gallon of sap a day!



*Graduate student Ren Klug taps a tree at MU Baskett Forest in Ashland, Mo.*

Syrup yields per tap can be estimated from the sap yield and sugar content data. Sugar maples had the highest estimated syrup yields at 0.16 gal/tap with bucket collection and 0.32 gal/tap with vacuum collection. Black walnut trees produced an estimated 0.04 gal/tap and 0.03 gal/tap of syrup with bucket and vacuum collection, respectively. The low sugar content of sycamore translated to lower syrup yields, estimated to be 0.003 gal/tap and 0.09 gal/tap of syrup with bucket and vacuum collection, respectively.

Landowners with non-veneer quality black walnuts or an abundance of sycamores can use this information to consider taking on a syrup operation. Sycamore and black walnut trees yield less syrup than sugar maples, but their syrup sells for higher prices, often over $300/gal, compared to $60/gallon for sugar maple syrup. There is only one commercial sycamore syrup producer in the US and few commercial black walnut syrup producers, leaving the field open for Missouri to expand in this niche industry. *—Ren Klug, Benjamin Knapp, Chung-Ho Lin*

### Evaluating forest farming practices for medicinal plant cultivation in Missouri

Forest farming is the practice of producing plants and fungi for food, medicine, and crafts under a forest canopy. Many shade-loving species are both nutritious and valuable. Unfortunately, many important medicinal plants such as ginseng and goldenseal are threatened because too many have been harvested from the wild. Forest farming offers a more sustainable way to produce these plants by managing the forest.

Managing forests can improve their health and productivity. Two common methods are prescribed burning and timber stand improvement. Timber stand improvement involves selectively cutting canopy trees to reduce competition and increase the sunlight that reaches the forest floor. Timber stand improvement is a particular type of thinning. Prescribed burning is the careful use of fire to reduce the amount of leaf litter on the forest floor. It can also decrease the number of shrubs and other woody plants. While both practices can be used to improve the health of a forest, they may also help create a better growing environment for forest farmed plants.

To study how timber stand improvement (thinning) and prescribed burning affect medicinal plant growth, we planted black cohosh, goldenseal, and wild ginger in four management types. One area had only been burned, one had only been thinned, one had been both thinned and burned, and one was left as the natural forest condition. The plants were observed over two years to see how many survived, how tall they grew, and whether they produced flowers and seeds. Taller plants that produce seed mean they are doing well under the management conditions.

This study also collected data on forest health to see how forest farming might affect other parts of the ecosystem. Soil chemical, physical, and microbial measurements helped us monitor changes due to our management. We also measured the understory plant diversity, including native and invasive species, to see how thinning and burning are changing the plant community. Monitoring these factors helps ensure forest farming does not harm the ecosystem.

Although this work is still in progress, early results show that fewer plants survived from year one to year two in all treatments. Black cohosh plants produced more flowers in the thinning management compared to the control and burn. This is likely due to increased light following the removal of some of the canopy trees. The thinning and burning treatments also influenced the composition of the understory plant community differently throughout time. Notably, the thinning only and burning only treatments had more native vegetation cover compared to the control. Our findings will continue to be developed with the goal to produce forest farming management recommendations for Missouri. *— Raelin Kronenberg, Benjamin Knapp, and Sougata Bardhan*

## Environmental Remediation

### Finding a needle in a haystack: An approach for determining priority pollutants in landfill Leachate

Landfills in the United States generate a considerable amount of leachate each year. Leachate is formed as water from precipitation percolates through the waste within landfills. As the leachate flows through the waste, it picks up contaminants. Leachate is commonly managed through off-site transport to a treatment facility, but this process can be costly.

On-site leachate treatment offers a lower-cost alternative to haul-and-treat operations. One type of on-site treatment is phytoremediation. In a phytoremediation system, trees are used to clean up contaminants in leachate. It is challenging to prioritize which pollutants in leachate to remediate. In the past, pollutant prioritization relied upon regulatory lists of leachate contaminants. Researchers have also used landfill leachate literature to identify priority contaminants. But regulatory lists are limited in scope, and information from the literature may not be representative of the site of interest. An approach that performs comprehensive, standardized pollutant prioritization is needed.

Therefore, we developed a framework for comprehensive landfill leachate pollutant prioritization. The framework combines modern analytical chemistry techniques with publicly available toxicity data. First, leachate samples are analyzed using mass spectrometry. This enables robust detection of pollutants in samples based on their unique spectra, or chemical fingerprints. Then, pollutants in the samples are putatively identified. The sample mass spectrometry data are compared to a reference database to identify matches. Finally, toxicity data for the identified contaminants are gathered from publicly available databases. These data are used to calculate a toxicity score for each contaminant. Pollutants are then ranked based on their toxicity scores. Pollutants ranked higher are more potentially

harmful. Phytoremediation systems can then be designed to target the highly ranked pollutants.

We applied our pollutant prioritization framework to a landfill case study. Landfill groundwater and leachate samples were collected from two Wisconsin landfills. From these samples, we putatively identified and prioritized 242 contaminants. The top 25 highest ranked compounds included mainly pharmaceuticals and biocides. These classes of compounds are an emerging avenue for phytoremediation research. We also searched the sample datasets for 275 leachate contaminants from regulatory lists. Eleven regulatory compounds were putatively identified in the study datasets. This low number indicates that regulatory lists alone are insufficient for leachate pollutant prioritization. An approach which combines multiple sources of data, like our developed approach, is more suitable for comprehensive leachate pollutant prioritization.



*Top: Landfill operations at an active landfill site. Right: Landfill leachate sample processing in the laboratory. Photos by Elizabeth Rogers.*

Our prioritization approach is flexible and can be customized according to community priorities. Future work could incorporate additional pollutant parameters and mass spectral reference libraries. Additional studies that investigate leachate composition over time could be beneficial for informing phytoremediation system design.— *Elizabeth Rogers, Chung-Ho Lin, Ron Zalesny Jr.*

## Tree water use – an important component of pollution remediation

Maintaining clean air, soil, and water resources is essential for human health. Yet, pollution of these resources remains a major challenge facing the modern world. One option for tackling this problem is phytoremediation, which harnesses the natural processes of trees to clean up environmental pollution. A key factor in the success of phytoremediation systems is tree water use. It drives the uptake of pollutants from the soil into tree tissues, where they can be further broken down.

Poplar trees are ideal candidates for phytoremediation systems. Their rapid growth, ability to degrade contaminants, and elevated water use all promote remediation. However, remediation potential is not equal across poplar varieties. Each variety has its own unique physical and physiological characteristics that influence its water use strategy. Some rapidly reduce their water use during dry conditions, while others maintain more consistent water use over varying moisture conditions. Both strategies involve tradeoffs between productivity and water use. Successful phytoremediation systems will require careful selection of poplar varieties to balance these tradeoffs. However, information on water use strategies is not available for many poplar varieties. Therefore, we sought to investigate the water use strategies of three poplar varieties that are geographically relevant to the Midwest.

In our study, we measured water use of four-year-old poplar trees for 75 days during June-September. The trees were part of a phytoremediation system at a former waste dumping site in Southeastern Wisconsin. We assessed the tree-level and leaf-level physiological responses to environmental factors, including soil moisture and atmospheric dryness. We also measured leaf area dynamics using a canopy analyzer device. The canopy analyzer measures light intensity below and above the tree canopy to determine the amount of light that is "blocked" by the leaves, which it then uses to calculate tree leaf area.

We found that poplar varieties differed in size and leaf area dynamics, each of which was related to tree water use. The variety with the largest trees had the greatest water use (18 kg per tree, per day), while the smallest variety had the lowest water use (10 kg per tree, per day). For leaf area, one variety began losing its leaves much earlier (August) and more rapidly than the other two varieties, which demonstrated more gradual decreases in leaf area from August to September. Water use mirrored these leaf area trends. The poplar varieties also differed in their physiological responses to environmental factors. The variety with moderate water use had more dynamic responses to soil moisture conditions than the other varieties.

We found that considering tree water use alone is not sufficient for deciding which poplar varieties to use in phytoremediation systems. Instead, a combination of factors including total water use, seasonal trends in water use, and physiological response to environmental conditions, should be considered. Using varieties with complementary water use strategies, such as those studied here, may be a prudent option for maximizing the success of phytoremediation systems across variable climatic conditions. *—Elizabeth Rogers, Chung-Ho Lin, Ron Zalesny Jr., Ryan Vinhal*

## Bacterial community profiling of ore processing waste material in Michigan's Upper Peninsula

Copper mining activities during the 19th and 20th centuries generated substantial amounts of waste material known as "stamp sands". Stamp sands are the leftover material resulting from the mechanical crushing of ore-bearing rock, and resemble coarse, dark sand grains. Stamp sands were commonly discarded into and along the shoreline of Lake Superior in Michigan's Upper Peninsula. Today, these stamp sands tailings pose risks to human health and the environment, as they contain high levels of heavy metals and are prone to erosion. See page 10 for additional background on this project.

Phytoremediation and bioremediation are sustainable strategies that could be used to remediate stamp sands heavy metal contamination. Phytoremediation systems apply trees to immobilize heavy metals and prevent their movement throughout the environment. Similarly, bioremediation involves using bacteria to remediate heavy metals. Like trees, bacteria can immobilize heavy metals in the soil. Some bacteria can even transform heavy metals into less harmful forms. Though phytoremediation and bioremediation are complementary strategies for heavy metal remediation, their utility for stamp sands remediation has not been studied.

Thus, we established a pilot-scale phytoremediation system at the Sand Point Restoration Area of the Keweenaw Bay Indian Community (KBIC) in Baraga, MI. The area contains nearly 344,000 cubic meters of stamp sands that were originally discarded into Lake Superior around 13 km north of the site.





*A sap flow probe in a poplar tree. The probe measures sap velocity, which is used to calculate tree water use. Photo by Elizabeth Rogers.*

Over several decades, these stamp sands have been transported and deposited at the site via wind and wave action. The phytoremediation system was planted with fast-growing willow and poplar trees, which are recognized for their pollution remediation effectiveness.

We currently are investigating the soil microbial community composition at the site. We believe that over time, the stamp sands at the site have promoted the survival and growth of bacteria that are tolerant of heavy metals. Some bacteria at the site may even be able to transform heavy metals into less harmful forms. To test this hypothesis, we collected stamp sands samples from the site. We are working with the University of Missouri Metagenomics Core to perform gene sequencing of the samples. By sequencing, or reading the genetic code of, a particular portion of a specific bacterial gene, we will be able to identify the different bacteria in the stamp sands. From there, we can research the identified bacteria to determine if any are reported to transform heavy metals.

As we collected the soil samples at the site before we planted the phytoremediation system, these samples represent the site's "initial" bacterial composition. We will collect more soil samples as the trees in the phytoremediation system grow. We will then use the initial samples as the baseline for comparing future samples to. In this way, we will be able to identify the effect of the phytoremediation system on the soil bacterial community at the site. We believe that the trees will stimulate the populations of beneficial microbe detoxifiers that help remediate the toxic heavy metal contamination. Our overall goal is to produce information that could be useful in the management of other areas affected by stamp sands in the region. *—Elizabeth Rogers, Chung-Ho Lin, Ryan Vinhal, Ronald Zalesny Jr., Erin Johnston, Jacob Dessellier, Katherine Heckman, Evan Kane, Mackenzie Russell, Karena Schmidt, Madeline Webb*

## Exploring bioremediation applications for explosive-contaminated farmland

Across the world, explosive compounds, used in war or industry, make their way into agricultural soils. The potential impacts of that contamination on food security and productivity are still not fully understood. To ensure healthy soils and crops, steps must be taken to identify, quantify, and remediate these compounds in a way that is scalable, economical, and sustainable. Phytoremediation, the use of plants to break down or immobilize contaminants in the soil, is one agroforestry practice with large-scale potential for rehabilitating impacted farmland. Exploring the potential phytoremediation benefits of cover cropping, biofuel production or ecosystem restoration can reveal the various roles plants can play in maintaining resilient soils and communities.

Warm-season plants, which include most grasses, have been shown to be efficient remediators of organic compounds, like the explosives TNT and RDX (cyclonite). Because many different species with a wide range of ideal growth conditions fall into the category of warm-season plants, phytoremediation is highly adaptable to local climate and geography. That makes this strategy applicable to contaminated sites across America, at a lower cost than traditional physical and chemical remediation practices.

Liquid chromatography/mass spectrometry (LCMS-MS) analysis of soil samples from war-impacted agricultural land has shown a significant presence of TNT and RDX. In future work, these contamination conditions will be replicated in an experimental setting, to determine the ability of a grass species to remove these compounds from the soil. Additionally, forthcoming work will examine how biochar --- an organic material known to improve soil health --- might assist grass species in removing contaminants. *—Caspar Dowdy, Chung-Ho Lin*

## Multi-pronged strategies to reduce cadmium phyto-availability and plant uptake

California avocados are now being linked with heavy metal contamination and being refused entry into several international markets due to levels of cadmium above the allowable limits for human consumption. Our scientific team has been working with producers, local government and USDA to develop the short-term strategies to reduce cadmium levels in avocado fruits through the use of soil biochar amendments, optimized liming regime and foliar iron application to reduce cadmium uptake. Our findings have demonstrated that the biochar amendments, both 2.5 percent and 5 percent, significantly reduced plant uptake of the Cd by 17-20 percent. To our best knowledge, this is the first long-term study investigating the effects of the combination of biochar, liming and foliar Fe applications on reducing Cd uptake by mature 1.5-year-old avocado trees. The information provided by this project will be shared for utilization with avocado growers, industry officials, the California Avocado Commission, the Hass Avocado Board, and avocado breeders. This will be done through sharing of data and results along with recommendations through the development of extension-type materials and outreach. The recommended production and breeding practices should allow US avocado growers to reduce cadmium levels in exported fruit, thereby eliminating this trade barrier. *—Chung-Ho Lin*



## Biodegradable plastic mulch in nursery and agricultural systems

The widespread use of non-biodegradable, petroleum-based plastic mulches in nursery and agricultural production has become a significant and growing environmental concern. Conventional plastic mulches contribute to persistent soil contamination, landfill accumulation, and the generation of microplastics that can migrate into terrestrial and aquatic ecosystems. These impacts are particularly problematic in intensive nursery and specialty crop systems, where plastic mulch use is frequent and removal after use is labor-intensive, costly, and often incomplete. In response to these challenges, there is an urgent demand for biodegradable plastic mulches that can maintain agronomic performance during crop production while fully degrading into environmentally benign end products such as water and carbon dioxide after use. Poly(vinyl alcohol) (PVA) represents a promising candidate material due to its water solubility, transparency, favorable mechanical and thermal properties, and excellent oxygen barrier performance. With the partnership with FT International Co., Ltd., the findings from our study demonstrated >40 percent degradation of Poly(vinyl alcohol) within five months. These outcomes provide a strong scientific foundation for transitioning nursery and agricultural systems toward sustainable, fully degradable mulch technologies, supporting environmental stewardship, regulatory compliance, and long-term soil health. *—Nahom Ghile, Arindam Mandal, Bani Kumar Biswas, Chung-Ho Lin, & Oliver Chen, CEO of FT International Co., Ltd.*

# Soil Health

## Soil microbes, agroforestry, and whole-farm stewardship

Across the Midwest, perennial agroforestry crops such as chestnuts and hazelnuts are expanding on farms that seek more resilient and profitable systems. These crops offer long-term stability, carbon storage advantages, and diversified income. Beneath these visible benefits is a deeper foundation: the soil holobiome, which includes microbes, fungi, roots, viruses, and biochemical interactions that collectively drive the performance and sustainability of perennial systems. My research examines how this living soil community develops, how it supports perennial crop function, and how it can guide whole-farm agroforestry stewardship.

At the University of Missouri, we continue to find funding for a comprehensive study using a 15-year chestnut and wheat agroforestry chronosequence at Cedar Hill Farm in central Missouri. Because the orchard was planted in consecutive annual blocks, trees of different ages share the same soil type, climate, and management history. This design allows us to observe how the chestnut rhizosphere microbiome forms, stabilizes, and influences soil processes as orchards mature. Using Hi-C sequencing, shotgun metagenomics, and RNA Seq, we map the microbial networks that support nutrient cycling, stress tolerance, and perennial crop resilience. Coupling these data with soil carbon, nitrogen, pH, enzymes, and micronutrients provides a comprehensive understanding of how soil biology shapes productive agroforestry systems.

We apply similar approaches to tallgrass prairie species to understand how soil microbes influence establishment and reproductive success in ways that inform agroforestry plantings, native seed production, and multifunctional perennial buffers. Prairie species such as Leadplant (*Amorpha canescens*), Southern Prairie Aster (*Eurybia hemispherica*), and Eastern Gamagrass (*Tripsacum dactyloides*) depend on intricate interactions between roots, microbes, nutrients, and soil chemistry. These interactions often decline in non remnant soils, which limits seed viability and reduces the success of restoration or agroforestry understory diversification. By mapping rhizosphere conditions, microbial communities, signaling molecules, and metabolomic profiles, we identify soil environments that allow these species to persist and reproduce. This work supports the National Seed Strategy and producers who are incorporating native perennials into agroforestry landscapes.

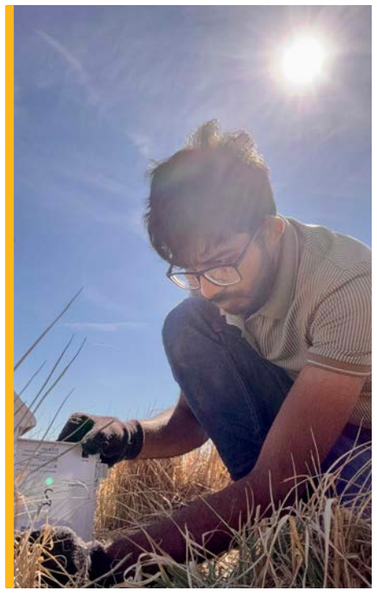
This research reinforces a broader point for perennial agriculture: soil health is not only chemistry; soil health is ecological structure and biological organization. In natural and semi-natural systems, high soil carbon or nutrient levels do not always predict high ecological integrity. Vegetation reflects belowground processes as well as the history of land use, disturbance, and succession. Understanding this distinction helps producers manage soils in ways that align with ecological processes rather than relying only on inputs.

These insights also extend to grazing systems that integrate agroforestry. Distributing grazing pressure, protecting sensitive areas, and maintaining perennial cover help stabilize soils and allow microbial networks to recover. Managed grazing that incorporates rest, reduced stocking pressure, and intentional movement of animals improves soil structure, root depth, and nutrient cycling. As microbial communities recover, they support higher water infiltration, greater organic matter retention, and improved floristic quality. These outcomes increase resilience to drought, enhance habitat, and strengthen long-term productivity in diversified agroforestry operations.

Across chestnut systems, prairie integrated plantings, and grazing lands, our research supports a unified vision. Healthy soils, productive perennial systems, and resilient farm ecosystems are all grounded in a deeper understanding of the soil holobiome and its role in whole-farm stewardship. *—Samuel Lord*

## Soil moisture patterns in kernza®, alfalfa, corn–soybean, and pin oak systems in northeast Missouri

Soil moisture plays a central role in crop performance and long-term soil health. This is particularly important in claypan soils, where water movement is slow during rain events and the surface can dry quickly during dry periods. This study aimed to quantify water use by various cropping systems, including alley-cropping agroforestry as compared to corn–soybean rotations.



*Graduate student Pradeep Nimantha checks soil-moisture loggers at the Ross Jones Research Farm.*

We monitored four systems at the University of Missouri's Ross Jones Research Farm. The systems were Kernza®, alfalfa, a corn-soybean rotation, and young pin oak trees forming an alley-cropping practice. Soil moisture was recorded hourly at 10, 20, 30, and 60 cm during two full years. The study focused on investigating seasonal and depth-wise moisture patterns and identifying where each system showed its strongest influence.

Season was the dominant driver of soil moisture across all systems. Moisture was highest in winter and remained relatively high into early spring when rainfall often replenishes the surface layers. Drying intensified through late spring and summer and reached its lowest levels in late summer and fall. Depth also influenced soil moisture fluctuations. The upper 10 and 20 cm layers responded immediately to rainfall and drying, while the 60 cm layer remained comparatively stable. Corn-soybean had its strongest impact in the shallow 10 to 20 cm zone. Kernza® drew most strongly from the mid-profile around 30 cm, while deeper layers stayed relatively stable. Alfalfa reduced moisture across the full 0 to 60 cm profile. Young pin oak showed early signs of deeper water use during active leaf growth.

These depth-specific differences show that each system places its strongest moisture demand in a different part of the soil profile. These findings elucidate that, on claypan soils where water movement is limited, such variation may support crop diversification, improving land use efficiency. In addition, systems with deeper uptake, such as alfalfa, may help reduce deep percolation losses and the leaching of nutrients from the agroecosystems.

Overall, this study provides baseline information on how four distinct annual and perennial systems influence soil moisture across different depth layers in claypan soils. These patterns offer a foundation for identifying system combinations that may improve moisture management, protect soil resources, and enhance resilience. These results also provide a clear starting point for future work aimed at developing diversified cropping systems that take advantage of complementary water-use patterns on claypan soils. *—H.H. Pradeep Nimantha, Morgan P. Davis, Ranjith P. Udawatta , Bienza Gurmessa, C.A. Righi*

## Unlocking the chemical secrets of disease-fighting soils

Farmers have long known that organic farming and the use of "cover crops" (plants grown to protect the soil rather than for harvest) can make soil healthier. Specifically, these practices help the soil naturally fight off plant diseases, a clear benefit known as "disease suppression." However, scientists have not fully understood the specific chemistry happening underground that makes this natural defense possible. Our research aimed to solve this mystery by looking at the chemical fingerprints of the soil

The study focused on the "rhizosphere," which is the biologically active layer of soil that surrounds plant roots. We believed that the interaction between plant roots and helpful soil bacteria creates a chemical environment that prevents harmful pathogens from growing. To test this, we used a cutting-edge scientific method called "untargeted metabolomics."

Think of metabolomics as taking a detailed snapshot of every chemical present in a sample. We collected soil from fields that have been farmed organically for a long time using cover crops. We then compared these samples to organic fields without cover crops and to standard conventionally managed fields.

Using advanced laboratory scanning technology (Liquid





*Doctoral student Nahom Ghile condcuts metabolomic analysis on soil samples in the Lin Lab.*

chromatography Mass Spectrometry), we were able to identify over 2,500 distinct chemical compounds in the soil. The results showed a clear difference: the soils treated with long-term cover crops had a significantly higher variety and abundance of "bioactive" chemicals compared to the control fields.

This discovery is significant because it provides the chemical proof for how healthy soils protect crops. It suggests that cover crops do not just physically cover the ground; they actively change the soil's chemistry to boost its immune system. By understanding these chemical profiles, we can better support farmers in using nature's own tools to grow healthy food without relying heavily on synthetic pesticides. *—Nahom Ghile, Chung-Ho Lin*

## Nitrogen dynamics in corn cropping systems with delayed termination of cover crops: A $^{15}$N study

A clear understanding of nitrogen (N) dynamics for cover crops (CC)-integrated corn (*Zea mays* L.) cropping system is essential for optimizing N management. This study investigated the N dynamics within a CC-corn system using $^{15}$N isotope enrichment method with delayed termination of CC. The treatments included CC species of cereal rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* L.), crimson clover (*Trifolium incarnatum* L.), and red clover (*Trifolium pratense* L.), along with no CC controls with fertilizer (NCC+15) and without fertilizer (NCC_NN). $^{15}$N-labeled Ammonium Nitrate (10% atom) fertilizer was injected at 15 and 30 cm (FID) in a split plot design. Biomass and soil samples were collected at corn planting, CC termination, and V9 and R6 stages of corn. Drier conditions resulted in poor germination in clover varieties. At CC termination, the greatest CC biomass and total nitrogen (TN) were recorded by hairy vetch with $^{15}$N applied at 30 cm (biomass: 7352 kg ha$^{-1}$, TN: 244 kg N ha$^{-1}$) and cereal rye with 15N applied at 15 cm (biomass: 5858 kg ha$^{-1}$, TN: 170 kg N ha$^{-1}$). The greater fertilizer-N recovery was recorded under cereal rye with 15N applied at 15 cm (51.2 kg N ha$^{-1}$), while the greatest biological nitrogen fixation (BNF) occurred under hairy vetch with 15N applied at 15 cm (101.5 kg N ha$^{-1}$). At corn V9 stage, corn biomass and fertilizer recovery were significantly lower under hairy vetch compared to no NCC+15N. At R6 stage, the greatest fertilizer recovery for corn biomass was under red clover (4.82 kg N ha$^{-1}$), while cereal rye (2.44 kg N ha$^{-1}$) and hairy vetch (2.4 kg N ha$^{-1}$) recorded significantly lower values. Corn yield was greatest under NCC+15N (12571 kg ha$^{-1}$), while cereal rye (8755 kg ha$^{-1}$) showing significantly lower yield compared to NCC+15N. Corn grain fertilizer recovery was greatest under NCC+15N (15.89 kg N ha$^{-1}$), while lowest recorded was in cereal rye (4.32 kg N ha$^{-1}$). However, yield under hairy vetch was not significantly different compared to NCC+15N. Corn fertilizer recovery was significantly greater at 30 cm FID compared to 15 cm at both V9 and R6 stages. Overall, CC species and N fertilizer application depth significantly affect N dynamics of CC and corn. Selection of suitable CC and deeper N placement have the

potential to improve fertilizer recovery and corn performance even with delayed termination of CC, while still receiving agronomic benefits of CC. *—R. Tharindu Rambadagalla, Gurbir Singh, Morgan P. Davis, Ranjith P. Udawatta*

### Long-term effects of cover crops on soil carbon forms and stocks under no-till corn-soybean rotations in the Midwest

Anthropogenic activities have disrupted the natural carbon (C) balance, contributing to global climate change. Cover crops facilitate C sequestration, but their long-term effects and deep soil C storage in Missouri remain unexplored. This study examined soil C forms to 1-m-depth under cover crop management in corn (*Zea mays* L.) – soybean [*Glycine max* (L.) Merr.] rotations. Soil from five- and 10-year-old cover crop fields in Missouri were sampled to 100 cm under no-till cover crop (CC) and no-till no-cover crop (NCC) treatments. Soil was analyzed for soil organic carbon% (SOC%), potentially mineralizable carbon (PMC), and permanganate oxidizable carbon (POXC). Cover crops increased SOC% and stocks in both fields, with the greatest concentration at 0-5 cm. Cumulative SOC stocks for 0-60 cm under CC were 10.3% greater in 10-year-old field and 1.63% greater in 5-year-old field than NCC. Overall, the 10-year-old field showed greater values for all three forms of carbon than the five-year-old CC field. Significantly greater POXC values under CC were observed at 0-5 cm and 45-60 cm than NCC in 5-year-old site. Additionally, PMC values were numerically greater for 0-5 cm depths under CC than NCC in both sites. Increased labile C (POXC and PMC) near the surface, suggests enhanced microbial activity and C mineralization. Greater changes in carbon forms were notable in shallow depth (0-45 cm) but less pronounced at deeper soils (45-100 cm). These findings highlight the potential for long-term cover crop adoption in enhancing soil C storage in Missouri, including in deeper soil, thereby contributing to climate change mitigation. *—R. Tharindu Rambadagalla, Morgan P. Davis, Gurbir Singh, Timothy Reinbott, Ranjith P. Udawatta*

### Soil microbial dynamics during a single cropping season as influenced by cover crops and tillage systems

Cover crops (CC) can enhance soil health, but their effects on soil microbial dynamics under varying tillage during a single growing season remain poorly understood. This study evaluated soil microbial dynamics under CC and different tillage regimes during a single season of soybean [*Glycine max* (L.)]. The study was conducted at the Plant Material Center, Elsberry, Missouri., with annual crop rotations alongside grass buffers and forested areas. Treatments included no-till CC (NC), conventional-till no-CC (CN), no-till no-CC (NN), grass buffer (GB), and deciduous forest. Soil samples were collected in March, July, and October 2023 from the 0-10-cm depth, and microbial properties were analyzed using phospholipid fatty acid (PLFA) analysis. In July, NC treatment had significantly greater ($p<0.05$) total microbial biomass, total bacterial biomass, Gram+ bacteria, Gram- bacteria, actinomycetes, arbuscular mycorrhizal biomass, and the lowest Gram+ to Gram- ratio compared to CN and NN, despite drought conditions. Additionally, NC had the numerically greatest microbial biomass values at all sampling times, except total bacterial biomass in October and total fungi biomass in March and October, along with greater organic matter percentage.

This study emphasized that the effects of CC and tillage on soil microbial dynamics may not be significant throughout the crop growing season; however, their influence becomes more pronounced under extreme environmental conditions such as drought. This study highlights the critical role of CC and no-tillage systems in enhancing microbial abundance and soil health, and soil resilience under drought stress conditions contributing long-term agricultural sustainability on cropping systems. *—R. Tharindu Rambadagalla, Biyensa Gurmessa, Ciro A. Righi, Morgan P. Davis, Ranjith P. Udawatta*

## Silvopasture

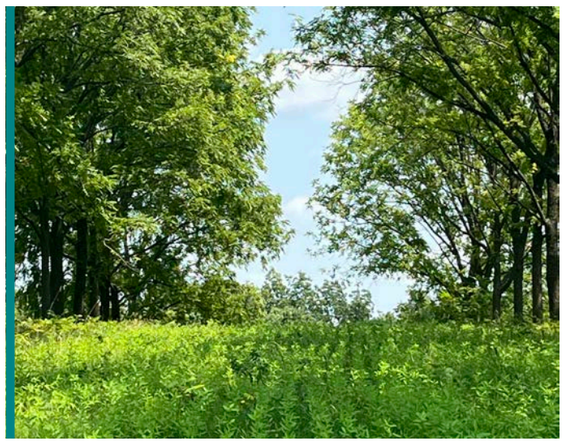
### Sunn hemp as a novel forage in pine or walnut silvopasture

Identifying warm-season forages that tolerate shade is essential for maintaining adequate grazing in silvopasture systems during the hot summer months. Sunn hemp, a warm-season annual legume, is known for producing high-protein, highly digestible forage in open pastures, but its performance under shaded silvopasture conditions is not well understood.

This study evaluated the forage production and nutritive value of sunn hemp grown in mature pine and black walnut silvopastures compared with open pasture. Sunn hemp was planted in all treatments on June 26 in both 2024 and 2025 at a seeding rate of 40 lb/acre. Pasture height was measured every two weeks after planting. Forage samples were collected every 10 days beginning 30 days after planting (DAP) and analyzed for forage mass, fiber and protein concentration, and plant height.

Sunn hemp forage production was highest in the open pasture at 40, 50, and 60 DAP, producing 1,878; 2,274; and 4,057 lb/acre, respectively. Forage yields under pine and walnut shade did not differ from each other at any sampling date. Maximum forage production under pine and walnut was 946 and 1,010 lb/acre, respectively—approximately a 75% reduction compared to open pasture.

Crude protein (CP) concentration was higher in the pine silvopasture (20.2%) than in the open pasture (16.9%). CP concentration in the walnut silvopasture (18.2%) did not differ from either pine or open pasture. As expected, CP declined as plants matured. Neutral detergent fiber (NDF) did not differ among treatments and remained stable through 50 DAP before increasing by 28% at 60 DAP. Acid detergent fiber (ADF) showed a similar pattern. Plant height increased steadily from 13 inches at 30 DAP to 37 inches at 60 DAP.



*Sunn hemp / black walnut silvopasture at the MU Horticulture and Agroforestry Research Farm. Photo by Harley Naumann.*

Overall, sunn hemp can contribute high-quality forage to silvopasture systems during summer, but substantial reductions in biomass under pine or walnut shade highlight an important tradeoff when integrating this species into shaded grazing systems.. *—Harley D. Naumann, Ellen M. Herring, Caitlyn T. Kleffner*

### Assessment of silvicultural interventions on ground flora in woodland silvopasture systems in the Missouri Ozarks

Long ago, Missouri's oak woodlands and savannas were open and sunny. These areas had many grasses and flowers with trees spaced far apart so sunlight could reach the ground easily. Today, the majority of these woodlands have been lost or have grown into thick, shady forests, making it harder for native plants to grow. They also do not provide the same habitat or resources they once did.



*MS student Emmanuel Oppong Adjei preparing to conduct a prescribed burn with a crew from Quail Forever. Photo courtesy of Quail Forever.*

Many landowners also want to raise livestock in ways that protect the land and bring in steady income. Silvopasture is one way to do this by growing trees, grass, and livestock together on the same land. When done carefully, it can support both healthy forests and productive farms. It may also help restore woodlands while giving farmers more options.

Our study took place at the Wurdack Extension and Education Center in the Missouri Ozarks to test this idea. We wanted to see if we could change a thick, shady woodland so more grass and plants could grow to feed livestock. We used three treatments: tree removal with one planned fire, more tree removal with one fire, and more tree removal with two planned fires. We also wanted to see if growing grasses would make a difference.

We measured how these treatments changed the forest and the plants on the ground. We also measured how much grass and other forage grew for future grazing.

All three treatments opened the tree canopy. Shade dropped from more than 80 percent to about 50, which allowed much more sunlight to reach the ground. Most small trees were removed. Plants became more varied and began producing more forage that livestock can eat. Within three years, forage growth was strong enough to support a modest level of grazing.

We found that removing some trees, growing grasses, and using planned fire can help woodlands heal and grow more food for farm animals. These steps let landowners care for Missouri's oak woods and still keep animals on the land. Our study shows that silvopasture can help both the land and the people who farm it in the Ozarks. *—Emmanuel Barffour Oppong Adjei, Ashley Conway-Anderson*

## Human Health

### Advancing the Missouri's Coronavirus Sewershed Surveillance Project Through Innovative Wastewater Epidemiology Applications

Since the beginning of the SARS-CoV-2 pandemic, Center for Agroforestry scientists and students have adeptly redirected





*Members of the Air and Wastewater Scientific Consortium sponsored by Inkfish, LLC.*

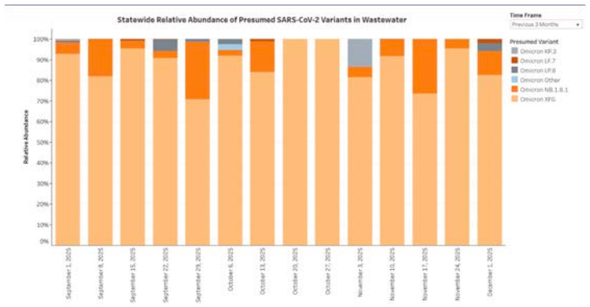
analytical resources and research expertise to collaborate with the 'Coronavirus Sewershed Surveillance Project' task force, sponsored by the Missouri Department of Health and Senior Services (DHSS), Department of Natural Resources (DNR), the Centers for Disease Control and Prevention (CDC) Epidemiology and Laboratory Capacity for Infectious Diseases (ELC) Program and the National Institutes of Health (NIH). The primary objectives of this project include: 1) utilizing domestic wastewater to assess the distribution of SARS-CoV-2, its variants and other human pathogens in Missouri, 2) identifying trends in SARS-CoV-2/variants prevalence to provide early warnings, and 3) monitoring indicators of SARS-CoV-2/variants reemergence to inform mitigation efforts.

The sewershed surveillance project has expanded to encompass testing at over 80 facilities each week. Our team's collaborative efforts have successfully averted numerous potential outbreaks in correctional facilities and communities. Furthermore, our team diligently tracks the spread of SARS-CoV-2 variants, such as omicron JN.1, KP.2, KP.3, NB.1.8.1, and XFG along with other sub-linkages, through routine weekly wastewater testing.

Since the declaration of the endemic state on April 1, 2022, in Missouri, wastewater-based surveillance has become increasingly crucial. This is due to the discontinuation of clinical testing programs by the state and the removal of the requirement for residents to report positive COVID-19 tests. Consequently, wastewater has emerged as the primary reliable tool for estimating the infected population, understanding the extent of virus control, closely monitoring variant progression, and capturing the early emergence of any new variants. The daily findings from our surveillance efforts aim to provide residents of Missouri with peace of mind as they started to resume their normal lives.

The wastewater epidemiology approach has been extended to other various pathogens, including monkeypox, influenza virus (flu virus), respiratory syncytial (RSV) and Candida auris in Missouri since 2022. As part of the national response plan addressing the escalating opioid crisis, UMCA scientists are collaborating with industry partners and the States of Ohio, States of Arkansas, Mississippi, Missouri and others to map the exposure and usage of opioids and illicit drugs at the community level. Collaborating with Missouri schools and communities to quantify >50 opioids, analogs, and metabolites in wastewater to support mitigation and intervention strategies. The state has committed $7 million to this testing for 2025/26 and the testing is being performed by our group. The research outcomes will serve as the evidentiary

foundation for implementing public health responses, such as treatments and education programs. Moreover, this methodology has the potential to assist the state in evaluating the efficacy of intervention, mitigation, and prevention strategies.




Center for Agroforestry scientists and students have been participating in the global charity initiative, the Air and Wastewater Scientific Consortium, sponsored by Inkfish LLC, a Washington limited liability company. This philanthropic consortium is led by David O'Connor and Shelby O'Connor at the University of Wisconsin and Marc Johnson at the University of Missouri.

Inkfish Wastewater Informatics and Wastewater Metabolomics: Led by Chung-Ho Lin, the Lungfish team in Missouri analyzed wastewater samples from Columbia, MO worked to develop methods to estimate stress levels as well as the use of medications for depression, anxiety, and stress. During 2025, the team successfully developed and validated methods to quantify > 25 biomarkers in the wastewater samples that enable real-time assessment of community well-being. The team also created an interactive dashboard to post and visualize this information. A prototype mobile application APP has been developed that integrates biomarker data with AI large language models, socioeconomic and demographic information, local events, and public clinical databases to provide real-time insights and recommendations.

The project has expanded to cover additional geographic regions, including Riverside, Calif.; Boston, Mass.; Boise, Idaho; Milan, Mo.; Ottumwa, Iowa; and Monett, Mo. Future work will incorporate additional biomarkers, including happiness-related hormones (e.g., dopamine, serotonin, and their metabolites) as well as other pharmaceuticals. These expanded datasets will be triangulated with socioeconomic stressors, local events, and clinical information, enabling cross-site comparisons and deeper insights into community health and well-being. *—Chung-Ho Lin*

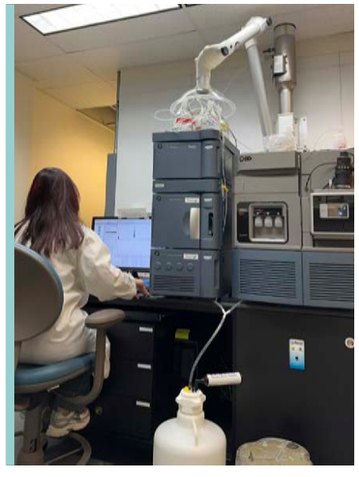
### Creating revenue streams for Missouri farmers and Native American entrepreneurs through the development of personal care products from Native American elderberry species

With the support from the MU CAFNR Joy of Discovery Program, this study explored the therapeutic potential of *Sambucus nigra* subsp. *canadensis* (American elderberry) cultivars, targeting wound healing and inflammatory skin diseases. Ethanolic extracts from leaves, stems, flowers, and berries were collected across different seasons and evaluated for their antibacterial, anti-inflammatory, and wound-healing activities. The results highlight the extracts' ability to modulate cellular metabolism under inflammatory conditions. This study underscores the therapeutic potential of American elderberry extracts in addressing inflammatory skin conditions and enhancing wound healing. Notably, several extracts emerged as promising candidates due to their dual ability to promote wound closure and regulate metabolic activity under inflammatory conditions. *—Isa Kupke, Chung-Ho Lin*

### Quantification of bioactive compounds in the juices of 21 American elderberry cultivars

American elderberry (*Sambucus nigra* subsp. *canadensis*) is recognized as a rich source of bioactive compounds with nutritional and therapeutic potential. However, comprehensive quantification of its metabolites remains analytically challenging due to the structural complexity of compounds and matrix interferences in juice extracts. A targeted ultra-high performance liquid chromatography-tandem mass spectrometry (UHPLC–MS/MS) workflow was developed and validated to quantify 22 bioactive metabolites, including anthocyanins, flavonoids, and phenolic acids, in juices from 18 wild-propagated accession and three established cultivars of American elderberry. The optimized UHPLC–MS/MS system demonstrated higher sensitivity, selectivity, and throughput compared to conventional high-performance liquid chromatography-tandem mass spectrometry (HPLC–MS/MS), achieving limits of detection and quantification below 0.1 ng/mL for most analytes. Matrix effects were effectively mitigated through sample dilution, enabling accurate and reproducible quantification across complex juice matrices.

Quantification of the bioactive metabolites in American elderberry juices revealed genotype-dependent variation in metabolite composition, highlighting opportunities for targeted breeding and cultivar selection to enhance desired phytochemical traits, such as antioxidant capacity, antiviral bioactivity, and overall nutritional quality. Notably, wild-propagated accession 1199 exhibited high levels of cyanidin-based anthocyanins, suggesting its utility as a natural food color source. Phenolic acid compounds were found most abundant in accession 1196, whereas the flavonoid isorhamnetin 3-rutinoside was found highest in the cultivar 'Ozark'.



*Doctoral student Amanda Dwikarina conducts metaboloic profiling in the Lin Lab.*

Overall, the high-throughput UHPLC–MS/MS method provides a robust analytical framework for sensitive, rapid metabolomic profiling that supports cultivar selection, quality assessment, and the development of elderberry-derived functional products. Its integration across breeding, production, processing, and commercialization enhances both scientific understanding and economic value, positioning American elderberry as a high-quality specialty crop with strong potential in the functional food and nutraceutical markets. *—Amanda Dwikarina, Chung-Ho Lin*

### Determining inhibitory effects of American elderberry (*Sambucus nigra* subsp. *canadensis*) compounds against *influenza* neuraminidase

*Influenza* is a prominent global health threat due to its ability to replicate and spread easily, prompting interest in immune support remedies such as American elderberry extract (*Sambucus nigra* subsp. *canadensis*). After budding from the host cell, progeny *Influenza* virions remain bound to the cell membrane through interactions between hemagglutinin on the viral envelope, and sialic acid residues expressed on epithelial cells of the throat and nasal cavity. Neuraminidase, an enzyme adjacent to hemagglutinin, then cleaves these sialic acid residues, enabling viral release. Due to its crucial role in viral transmission, neuraminidase is a popular target for anti-*Influenza* drugs such as oseltamivir (Tamiflu) which can occupy the active site of the enzyme, which prevents the enzyme from binding to sialic acid. This will result in no virion release from the host cell.

Despite the common use of American elderberry supplements, its exact mode of action in relieving symptoms of *Influenza* remains largely uncharacterized. This project aims to: (1) explore which bioactive compounds extracted from American elderberry can suppress Influenza neuraminidase activity, and (2) develop a high-throughput bioassay to screen any natural compound for inhibitory properties against neuraminidase.

Thirteen out of 14 American elderberry compounds exhibited varying levels of inhibition of Influenza neuraminidase activity in testing. The compound cyanidin 3-o-rutinoside exhibited no inhibitory effects, while isorhamnetin showed the highest percent inhibition of approximately 40%. It is possible that specific combinations of compounds could act synergistically, giving a greater inhibition than observed for single compounds, which will be pursued in future studies. Future work will test additional American elderberry compounds and evaluate juice from multiple cultivars to further characterize their inhibitory potential. Given the demonstrated inhibitory effects by American elderberry compounds, these results may drive the public's interest in elderberry supplement uptake, leading to it becoming a more popular immune support choice during flu season. *—Katherine Spitzmiller, Amanda Dwikarina, Hsin-Yeh Hsieh, Chung-Ho Lin*

### Assessing the effects of fire frequency and intensity on wood chemistry through modern metabolomics: Implications for chemical ecology and wood utilization

Wildfires are becoming increasingly frequent in *Pinus ponderosa* forests in the northern Sierra Nevada of California. Pinus ponderosa, commonly known as western yellow pine, is a large pine species widely distributed across North America. Its wood has a distinctive, pleasant aroma and is lightweight, making it useful for construction, furniture, and paper products. The tree's thick bark and deep root system help it survive and recover well from low-intensity wildfires, supporting forest regeneration. In addition to physical adaptations, yellow pine also responds to fire on a chemical level.

Fire can activate certain stress-response processes in trees, triggering them to produce a variety of helpful natural compounds such as polyphenols, terpenes, and alkaloids. These compounds have antioxidant, antimicrobial, and anti-inflammatory effects, which support the tree's ability to cope with harsh conditions. Our research shows that both the frequency and severity of forest fires can greatly change the chemical makeup of wood and resin. After fire, over 50 helpful natural compounds increase, many of which support wound healing, protect trees from microbes, and improve the durability and quality of the wood. In addition, in fresh wood samples, we also identified 43 different scent-related compounds that shape the pine tree's aroma and its role in the ecosystem.



*Grad student Phuc Hong Vo heads to her sampling site in Plumas National Forest, northern Sierra Nevada, Ca. Photo by Chung-Ho Lin.*

Some specific molecules become much more concentrated when the tree is under stress, showing how it activates its own chemical defenses. Under fire stress conditions, levels of these secondary chemicals often increase to improve the strength and biological functions of the wood.

In addition, and luckily for us, natural compounds like polyphenols, terpenes, and alkaloids stand out for their diverse health benefits and wide-ranging applications in medicine, nutrition, and cosmetics. Therefore, these fire-driven changes in metabolism not only help to explain how yellow pine stays resilient in tough conditions, but also produce valuable compounds that may be useful for sustainable bioproducts.

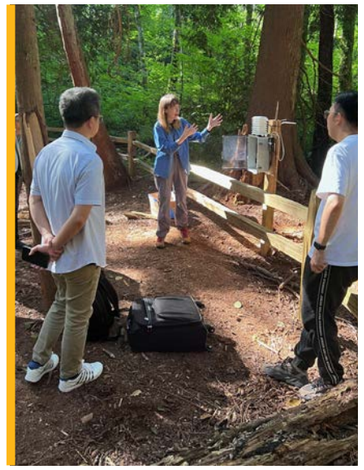
The results of our research will suggest new applications for pine wood in the cosmetic, perfume, and biomaterials industries and simultaneously shape a new value chain for post-fire forest resources. *—Phuc Hong Vo, Laura Marshall, Yoshua Yantis, Joseph Marschall, Dr. Michael C. Stambaugh, Chung-Ho Lin*

### Analyzing the health-promoting benefits of forest air in Missouri and beyond

Spending time in nature is widely believed to improve mental and physical health, but researchers are still uncovering what mechanisms cause this. Some scientists at Nippon Medical School in Tokyo have studied how people respond to repeated forest visits. They found that people who spent more time in the forest had less anxiety, stronger immune function, and more cancer fighting cells. While promising, these findings don't fully explain the mechanisms behind nature's health improving qualities.

Graduate student Ruth Williamson is investigating one factor that may shed light on why nature exposure improves people's health. Rather than looking at the human's response to nature exposure, she studies the chemicals plants release into the air to see what health benefits they may contribute. Plants emit a host of volatile compounds as they perform their day-to-day functions. These volatile compounds, known as phytoncides, give the outdoors its distinctive scent and help plants defend against pests and disease. When humans inhale phytoncides in a concentrated form, research suggests they can boost mood, enhance immunity, and promote anti-cancer activity.

To learn what role phytoncides play in nature exposure, Ruth is first identifying and measuring what compounds are present. Before this project detailed information on phytoncide levels in the Midwest did not exist. Williamson uses a machine called a



*Doctoral student Ruth Williamson explains the scientific theory and practical applications of phytoncide sampling to a group of international scientists from China and Canada. Photo by Chung-Ho Lin.*

thermal desorption gas chromatograph-mass spectrometer (TDU-GC/MS). Like a nose, the thermal desorption tubes collect compounds from the air. Then, like a brain, the TDU-GC/MS comprehends what is in the sample and provides a report. The report shows which compounds from the targeted list are present and how much of them are there.

So far, Williamson, and fellow graduate students Nahom Ghile and Phuc Vo, have sampled air during three seasons, spring, summer, and fall. The forested sampling location is near McBaine trailhead of the Katy Trail. They also collected samples in downtown Columbia as a non-forested comparison. Beyond Missouri, Ruth is working with scientists at the University of British Columbia to see how phytoncide levels change depending on forest type and location. She is also working to create a standardized method of phytoncide collection. This will increase the available information on phytoncides and make it easier to compare notes between labs. Early results from the sampling shows that the forest has a more abundant mix of the health-promoting compounds compared to the city. The data suggests that spring at midday has the highest phytoncide levels. So, to experience the most phytoncides try going on your walks during the spring on your lunch break.

The goal of this research is to go beyond just measuring these compounds. Williamson wants to understand how these phytoncides, at the concentrations found in the forest, affect people's health. Once this link is better understood, it can be used to show policy makers the value of forests for human health and present nature exposure as a scientifically backed preventative healthcare practice. *— Ruth Williamson, Phuc Vo, Nahom Ghile, Chung-Ho Lin*

## Mapping a culturally responsive future for Land of the Osages Research Farm

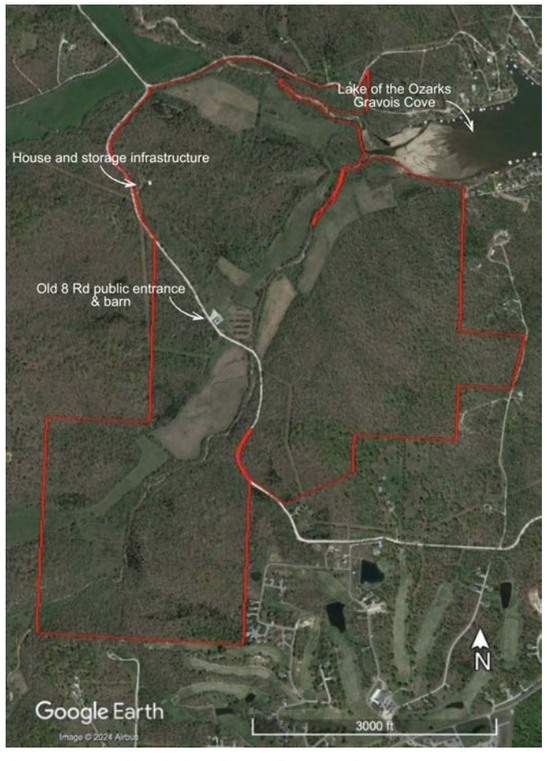
Land of the Osages Research Farm (LORF) is the newest addition to the MU Agricultural Experiment Station, established in 2019 at the generous bequest of our long-time partner, Mr. Doug Allen. The farm naming formally initiated a land-based connection with Osage Nation. We value this opportunity to recognize that many of the tree crops we promote today were tended on these lands for hundreds of years, primarily by the Osage, before European settlement. The farm's rolling Ozark hills and bottomland fields adjacent to Lake of the Ozarks are intended for agroforestry research, demonstration, and outreach that simultaneously honors Osage and Ozark communities' interests. Complicating this task, Osage Nation's reservation land in Northeast Oklahoma is 300 miles from the farm, and there are currently few Osage representatives in the MU community. Still, over the six years since the farm's establishment, an advisory committee including local Ozark land stewards, Osage Nation representatives elected by Chief Standing Bear, and MU affiliated local staff have come together to express our priorities.

A participatory place-based narrative inquiry of LORF was conducted over 2019-2025 as part of an effort to clarify a collective vision for the farm and to reflect on our experiences related to LORF thus far. The inquiry involved extensive document review, conversational interviews, reflexivity, and story mapping with local, MU, and Osage advisory committee members. The resulting dialogical narrative collage revealed three essential lessons related to pace, proximity, and process: (1) that a responsive capacity depends on the quality of our established relationships and reputations; (2) that physical presence on the farm greatly enhances a sense of community connection; and (3) that concerns around the pace of activity and productivity must be tempered with an attention to long-term vision for translational and relational engagement.

The inquiry also facilitated clarification of shared priorities that will guide our direction there moving forward:

1. Honoring Doug Allen's gift and Osage ancestry on these lands through respect for cultural knowledge and thoughtful partnership;
2. Committing to ecologically and culturally responsive research and education focused on native plants, silvopasture, silviculture and forest farming practices; and
3. Creating infrastructure for community value and learning that supports research translation and intercultural understanding.

Learn more on the Land of the Osages Research Farm Story Map spanning history, ecology, and experience.*—Hannah Hemmelgarn*




*An aerial view of Land of the Osages Research Farm, with property lines in red and visible adjacent land uses, depicting the landscape and its periphery, with landmarks. Graphic by Hannah Hemmelgarn.*



# Graduate Programs

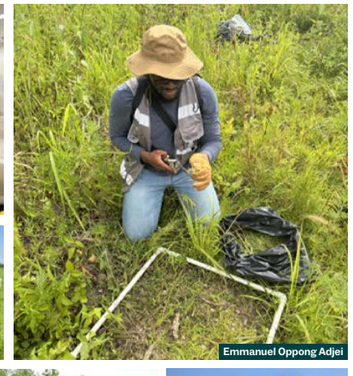
The Mizzou Center for Agroforestry's graduate programs continue to thrive with 44 students actively enrolled, including: eight doctoral students, four master's thesis students, 23 online master's students, and nine online graduate certificate students. Fifteen of these students enrolled this year, indicating ongoing interest in graduate-level academic opportunities in agroforestry.

Fourteen graduate student completed their degree programs this year, including four PhD dissertations, two master's theses, five online master's final projects, and three graduate certificates.

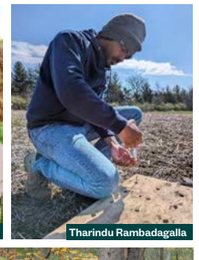
During 2025, Center faculty offered three core courses and three elective courses in the agroforestry emphasis area graduate curriculum. Total enrollment across the three core agroforestry courses in 2025 was 44. For 2026, the Center will be adding 3 new online course offerings: Tree Nut Production (summer), Site Suitability and Selection for Agroforestry Species (fall), and Social Dimensions in Agroforestry (fall).


Amanda Dwikarina


Kendra Esparza-Harris


Emmanuel Oppong Adjei


Elizabeth Rogers


Tharindu Rambadagalla


Hannah Hemmelgarn

**Congratulations to our 2025 graduates!**

**Doctoral Dissertations**

- Amanda Dwikarina, *Characterization of bioactive compounds in American elderberry juices*
- Kendra Esparza-Harris, *Interdisciplinary integration of silvopasture among livestock grazing systems as a strategy for natural resource management*
- Hannah Hemmelgarn, *Towards relational accountability at Land of the Osages Research Farm: A place-based narrative inquiry and story map*
- Elizabeth Rogers, *Enhancing the Phytotechnologies toolkit: From pollutant prioritization to assessing the water relations of* Populus L. *genotypes grown for phytoremediation*

**Master's Theses**

- Emmanuel Oppong Adjei, *Assessment of silvicultural interventions on ground flora in woodland silvopasture systems in the Missouri Ozarks*
- Tharindu Rambadagalla, *Cover Crops on nitrogen cycling, soil carbon storage, and soil microbes*

**Online Master's Projects**

- Joshua Allsup, *Agroforestry as a tool to enhance biointensive gardens in Nicaragua*
- Jennifer Blair, *Overcoming a marketing barrier: Elderberry research in plain language*
- Avery Drake, *Curriculum development for an undergraduate degree in agriculture and minor In agroforestry*
- Dana O'Malley, *Case study: Urban food forests – challenges, opportunities, and insights from the Syracuse Urban Food Forest Project*
- Xinyuan Shi, *Agroforestry cultivars database*

**Graduate Certificates:** Benita Lee, Jeremiah Gorske, and Matt Fagan

**Support our work!**

Donations to the Center for Agroforestry support research, outreach, and training to educate producers and natural resource professionals, enhance human health, and promote the resilience of our landscapes.

## Publications


Bishop, B. Cerro, F., Meier, N.A., Coggeshall, M.V., Fritschi, F., Revord, R.S. (in press). Characterizing Canopy Light Penetration in Black Walnut (*Juglans nigra*) Cultivars to Inform Selection for Alley Cropping. *Agroforestry Systems*. DOI: 10.1007/s10457-025-01377-4

Çerçioglu, M., Udawatta, R.P., Anderson, S.H. (2025). Use of cover crops for sustainable management of soil condition and health: a review. *Soil Security*. 18, p.100177. DOI: 10.1016/j.soisec.2025.100177

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Thomas, AL., Robbins, R.T., Allen, R.A., Kirkpatrick T., Bergmeier, E.A., Cabrera-Garcia, J., Harris, J.L., and Striegler, R.K. (2025). Distribution of Plant-parasitic Nematodes in Missouri and Arkansas, USA, Vineyards. *HortScience* 60:1903-1907. https://doi.org/10.21273/HORTSCI18858-25.


## Patents

Coggeshall, M.V., Revord, R.S., Meier, N.A., University of Missouri St Louis, 2025. Walnut tree named 'Hickman'. U.S. Patent Application 18/416,651. Patents.google.com/patent/USPP36382P2/en

## Selected Presentations

Dwikarina, A., Hsieh, H.-Y., Thomas, A. L., & Lin, C.-H. (2025, July). Elucidating antiviral mode of action of the bioactive compounds in American elderberry (*Sambucus nigra* subsp. *canadensis*) [Conference presentation]. 19th North American Agroforestry Conference, Columbia, MO, United States.

Hemmelgarn, H., & Warren, S. (2025, July). Growing a coordinated agroforestry training network within regional resource hubs [Conference presentation]. 19th North American Agroforestry Conference, Columbia, MO, United States.

Prenger, E., Meier, N., Thomas, A., Revord. R.S. (in press). Progress towards establishing an American Elderberry breeding program in the Midwest United States. Acta Horticulturae. IV International Symposium on Underutilized Plant Species. Fort Meyers, FL. October 20-24, 2025

Vinhal, R.A., Rogers, E.R., Shafqat, W., Kort, J., Renninger, H., Siegert, C., Zalesny, R.S. Jr. Submitted. Proceedings of the 14th biennial Short Rotation Woody Crops International Conference-The future is green: Integrating short rotation woody crops (SRWCs), agroforestry, and ecosystem services for sustainable, productive landscapes. Technical Paper of the International Union of Forest Research Organizations (IUFRO) Working Party 2.08.04: Poplars and Willows, Vienna, Austria. https://www.iufro.org/publications/technical-paper-of-working-party-20804-proceedings-of-the-14th-biennial-short-rotation-woody-crops-international-conference

Webber, J.B., Meier, N.A., Nauman, H., Revord, R.S. (in press). Multi-functional black walnut systems: nuts, timber, and alley cropping. Acta Horticulturae. IV International Symposium on Underutilized Plant Species. Fort Meyers, FL. October 20-24, 2025

## Funding

Almasri, M. (PI), Lin, C.H. (Key Personnel). Convergence Accelerator Track J Phase 2: rapid detection technologies and decision-support systems for safe, equitable food systems. NSF. 2024-2027. $5,000,000 [$10,000 to Lin, UMCA].

Beebe, G., Daily, M., Hemmelgarn, H., Stubblefield, K. Enhancing Farmer Case Studies & Field Visits for the Agroforestry Training Academy. NCR-SARE. 2025. $3,200.

Beebe, G. Enhancing Consumer Education through Recipe Distribution at the Missouri Chestnut Roast Festival. NRC-SARE. 2025. $1,300.

Fidalgo, M. (PI), Lin, C.H. (Co-PI). Hybrid filtration/AOP membrane process for point of use PFAS removal from drinking water. EPA. $100,000. 2024-2026. [$15,000 to Lin, UMCA]

Goerndt, M., Thomas, A., et al. Adaptation of Pasture and Forestland to Variable-density Silvopasture and Black Walnut Silvicultural Systems in Southern Missouri. $300,000. USDA-NIFA-Capacity Building Grants for Non-Land Grant Colleges of Agriculture. 2027. [$90,000 to Thomas]

Hemmelgarn, H. (PI). Edwards Mother Earth Foundation (subaward, Appalachia Sustainable Development). Agroforestry Training for Natural Resource Professionals. 2023-2025. $88,541

Hemmelgarn, H. (PI). Agroforestry Trainings for Natural Resource Professionals. Edwards Mother Earth Foundation, subaward from Appalachian Sustainable Development. 2025-2027, $96,162

Hemmelgarn, H. (PI), Walter, W., Wildcat, M., Hayman, J. (Co-PIs). USDA NIFA New Beginning for Tribal Students program. MU-Osage Food and Agriculture Program for Tribal Student Engagement and Success. 2021-2025. $250,000.

Hemmelgarn, H. (PI), Stubblefield, K. (Co-PI). USDA SARE Professional Development Program. Establishing a Professional Agroforestry Certification and Learning Network for Education and Exchange. 2023-2026. $119,962.

Hemmelgarn, H. (PI), Daily, M. (Co-PI). The Corps Network, National Association of Conservation Districts, USDA Natural Resources Conservation Service. Working Lands Climate Corps. 2024-2025. $111,373.

Hemmelgarn, H. (PI). Developing Technical Training Best Practices and Agroforestry Resources for Technical Assistance Providers. USDA Forest Service Joint Venture Agreement 25-JV-11132650-228. 2025-2028, $140,000.

Hemmelgarn, H. (PI). NIFA CBG. Building a Forest Farming Network to Support Greater Farm Diversity and Enhanced Ecosystem Services in the Midwest. Subaward from Lincoln University, 2024-2027, $74,844

Johnson, M. (PI), Lin. C.H. (Co-PI). Coronavirus sewershed surveillance project. The Missouri Department of Health and Senior Services/CDC Epidemiology and Laboratory Capacity for Infectious Diseases (ELC). Program. 2020-2027. $19,200,000 [$9,600,000 to Lin, UMCA]

Krishnaswamy, K. (PI), Lin, C.H. (Co-PI). Seeding circular economy for upcycling food industry waste. USDA-NIFA. 2023-2025. $299,000 [$14,950 to Lin, UMCA]

Knapp, B (PI). USDA NIFA. Agroforestry for climate risk management: effectiveness of windbreaks in reducing crop loss. 2022-2026. $234,644.

Knapp, B.O. (Co-PI), Stambaugh, M.C. (Co-PI). Sustainability of uneven-aged oak forest management in the Missouri Ozarks: how are current practices affecting white oak regeneration and recruitment? Missouri Department of Conservation. 2022-2025. $314,511 [$157,255 to Knapp].

Knapp, B.O. (PI), Kabrick, J.M. (Co-PI), Pile Knapp, L.S. (Co-PI). Can we facilitate the rapid establishment of functional pollinator habitat in log landings? USDA Forest Service, Northern Research Station. 2020-2025. $136,631

Kronenberg, R.L. (PI). Soil microbial affiliations with three temperate forest herbs, goldenseal, black cohosh, and wild ginger, in a managed forest farm. The Garden Club of America, Anne S. Chatham Fellowship in Medicinal Botany. 2025-2026. $4,500.

Kronenberg, R.L. (Co-PI) and Knapp, B.O. (PI). Assessing the survival and expansion of four native forest herbs in a Missouri Ozark Forest Farm. Land of the Osages Research Farm Research Fund. 2025-2026. $28,346.

Lin, C.H. (PI) and Elizabeth Rogers. Using specialized trees and biochar to remediate and stabilize mining waste for the Keweenaw Bay Indian Community. USDA-Forest Service. 2024-2027. $259,000.

Lin, C.H. (PI). Impact of long-term cover cropped organic farming practices on the development of disease suppressive soils. USDA-NIFA/Lincoln University. 2022-2026. $860,000 [$450,000 to Lin, UMCA].

Lin, C.H. (PI). Opioid wastewater testing. 2022-2026. $300,000.

Lin, C.H. (PI). Center of Excellence-Soil Health. Plant Health and Human Health. 2022-2025. $42,000.

Lin, C.H. (PI). Phytotechnologies for Rural and Urban Communities. USDA Forest Service. 2023-2026. $69,000.

Lin, C.H. (PI) and Rogers, E.. Enhanced Forest Productivity via Phytostabilization with the Keweenaw Bay Indian Community. USDA-Forest Service. 2025-2029. $146,000.

Lin, C.H. (PI) and Rogers, E. A comprehensive re-assessment of stand development and implication for timber management guidelines. USDA-Forest Service. 2025-2029. 2025-2030. $190,000.

Lin, C.H. (PI) Data-Driven Assessment of Environmental Contamination in Soils & Crops Impacted by Demining Activities in Ukraine. 2025-2026. Howard G. Buffett Found. $15,000.

Meier, N. (PI). Pilot Scale Hazelnut Processing Lab. Specialty Crop Block Grant subrecipient. Missouri Department of Agriculture. $49,901.

Mendoza-Cozatl, D. (PI), Lin, C.H. (Co-PI). Reducing trade barriers for U.S. exports of avocado fruit through multi-pronged strategies to reduce cadmium phyto-availability and plant uptake. USDA Technical Assistance for Specialty Crops Program, Commodity Credit Corporation and USDA Foreign Agricultural Service. 2022-2025. $499,000 [$250,000 to Lin, UMCA].

Myers, R. (PI), Udawatta R.P (Co-PI), et al. USDA-NRCS. Partnership for Climate-Smart Commodities grant. 2022-2027, $25,000,000.

Myers, R. (PI), Udawatta R.P. (Co-PI), et al. USDA-NIFA. Catalyzing cover crop advancement as a climate smart practice through a national variety improvement and seed production program. 2023-2028. $10,000,000. [$192,537 to Udawatta, UMCA].

Neupane, J. (PI), Thomas, A. (co-PI), et al. 2024-2026. Sensor-based Irrigation Management System (SIMS) – A Climate Smart Approach to Specialty Crop Production in Missouri. $48,191. Missouri Department of Agriculture, Specialty Crops Block Grant Program.

O'Connor, S. (PI), O'Connor, D. (PI), Johnson, M. (PI), Lin, C.H. (Collaborator). Air and Wastewater Scientific Consortium. Inkfish LLC. 2025-2030. $22,000,000 [Total 30M, 10M to MU and $3,300,000 to Lin, UMCA].

Reinbott, T. (PI), N. Aloysius and R.P Udawatta (Co-PIs). USDA-Specialty crop block grant program. Development of smart farm irrigation tool kit for smallholder vegetable producers. 2022-2025. $49,973.

Revord, R. (PI). DNA Fingerprint Development for Identification of Elderberry Cultivars. $49,941. Missouri Department of Agriculture, Specialty Crops Block Grant Program. 2024-2025. $49,941.

Revord, R., (PI) and Coggeshall, M., (co-PI). Revitalization of Pecan Research and Breeding for Missouri. Missouri USDA Specialty Crop Block Grant. 2023-2025. $47,704.

Revord, R., (PI), Holliday, J., (co-PI) and Westbrook, J. Accelerating Marker-Trait Association Studies in Chestnut (Castanea spp. and hybrids). USDA-NIFA, Plant Breeding for Agriculture Production Program Area. 2021-2025. $563,626. [$307,982 to Revord, UMCA]

Revord, R.S (PI), Meier, N.A. (Co-PI), and T. Molnar (co-PI). Exiting the breeding pipeline – meeting demand for commercial hazelnut cultivars in the eastern U.S. USDA-NIFA-Agriculture and Food Research Initiative. 2024-2027. $448,458 [$298,458 to Revord, UMCA]

Schafer, J. et al. 2024-2028. Advancing Organic Agriculture in the Mid-South: Phase II – Refining Solutions for Essential Challenges. Grant is $999,908. MU share $145,826. USDA-NIFA-Organic Agriculture Research and Extension Initiative (OREI). Led by Winrock International.

Stambaugh, M. (PI), Lin, C.H. (Co-PI). Assessing fire impacts and benefits from restoration and fuel treatments to hard/yellow pine wood properties and volume production, ecosystem amenities and industry stakeholder perceptions. USDA-Forest Service. 1/1/2024-12/30/2027. $1,200,000. [$500,000 to Lin, UMCA]

Sutovsky, P. (PI), Lin, C.H. (Co-PI). Paternal residential exposure to unconventional oil and natural gas extraction (UOG). National Institute of Environmental Health Sciences, NIH R21. 2022-2025. $450,000. [$150,000 to Lin, UMCA]

Thomas, A.L. (Co-PI), Byers, P.L. (Co-PI), Sommers, S. (Co-PI), Volenberg, D. (Co-PI), and O'Neal, C. (Co-PI). Muscadine Grapes: A Potential New Specialty Crop for Missouri. Missouri Department of Agriculture, Specialty Crops Block Grant Program. 2026. $28,248.

Thomas, A.L. (PI), Byers, P.L. (Co-PI), Tian, P. (Co-PI), and Schoelz, P. (Co-PI). Developing an Understanding of the Virus Situation with Missouri Elderberry. Missouri Department of Agriculture, Specialty Crops Block Grant Program. 2023-2025. $49,804.

Thomas, A.L. (PI), Lin, C.H. (Co-PI), Revord, R.S. (Co-PI), and 32 others. Moving American Elderberry into Mainstream Production and Processing. USDA-NIFA-Specialty Crop Research Initiative (SCRI). 2021-2026. $5,345,225. [$1,270,000 to Thomas, Lin, Revord, UMCA]

Udawatta, R. (PI), Hemmelgarn, H. (Co-PI). New Roots for Restoration Biology Integration Institute. National Science Foundation (subaward, Danforth Plant Science Center). 2021-2026. $855,109.

Wan, C. (PI), Lin, C.H. (Co-PI). Functionalized Nanocelluloses for Effective Removal of Per- and polyfluoroalkyl Substances. USDA Forest Service National Forest Product Laboratory. 2024-2026. $344,468. [$17,223 to Lin, UMCA]



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